PLATFORM MOTION AND SIMULATOR TRAINING EFFECTIVENESS

PAUL W. CARO
Seville Research Corporation

SUMMARY

Several recent studies reported that simulator motion did not benefit subsequent flight performance. Other studies have reported various effects of motion upon pilot performance in simulators. These possibly contradictory findings are examined in the light of recent distinctions made between maneuver and disturbance motion. The studies in which simulator motion did not benefit transfer predominantly employed maneuver motion cues, whereas the other group of studies incorporated more disturbance motion cues. Pilot reactions to simulator motion also were examined in terms of maneuver vs. disturbance motion, and it was noted that judgments of the training value of simulator motion were related to the maneuver-disturbance distinction. It is concluded that maneuver motion may be of little potential training value, under many circumstances, and data necessary to an adequate simulation of disturbance motion may not be available. An analysis of the training requirements associated with disturbance motion is needed.

MOTION AND TRANSFER OF TRAINING STUDIES

Although motion simulation represents a significant portion of the cost of simulator procurement and operation, the investigation of the influence of motion upon transfer of simulator training to operational aircraft has been largely ignored. There were a number of studies of simulator motion in relation to aircraft handling qualities and control during the 1950s and 1960s, but most of them addressed transfer of training only indirectly. The first significant published transfer of training study of the effectiveness of simulator motion upon subsequent performance in flight was reported in 1975 by Jacobs and Roscoe.

Jacobs and Roscoe reported that pilot performance in the aircraft did not benefit from the presence of normal washout cockpit motion in the simulator. In that study, training received in the GAT-2 in a two-axis (pitch and roll) normal washout motion condition, compared with training in the same device without motion, resulted in nonsignificant differences in amount of transfer to the aircraft for those two conditions. There was, however, significant positive transfer for both motion and no-motion conditions. Similar results have been obtained in a U.S. Air Force undergraduate pilot training study involving the more sophisticated six-axis motion system associated with the Advanced Simulator for Pilot Training (ASPT) (Woodruff, 1976).

MOTION AND SIMULATOR PERFORMANCE STUDIES

The findings in these two recent studies that the presence of motion did not increase simulator training effectiveness is of considerable interest, since there are other studies showing that, at least under some circumstances, motion does influence simulator training. For example, Fedderson (1962) 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. A recent U.S. Air Force study of pilot responses to engine failure in a simulated transport-type aircraft found that training is more effective when motion is added to a simulator with a visual display than when the same simulator and visual are used without motion (DeBerg, McFarland, & Showalter, 1976).

Further, there is evidence that pilot performance differs as a function of the presence or absence of motion. For example, Perry and Naish (1964) found that pilots respond to external forcing functions such as side gusts more rapidly, with more authority, and in a more precise manner in a simulator with motion and visual cues than when only visual cues are present. NASA researchers (Rathert, Creer, & Sadoff, 1961) found that the correlation between pilot performance in an aircraft and in a simulator increased 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 ASPT study (T-37), motion may have no effect.

In another NASA study (Douvillier, Turner, McLean, & Heinle, 1960) of the effects of simulator motion on pilot's performance of flight tracking tasks, the results from a moving base flight simulator resembled the results from flight much more than did those from a motionless simulator. In a British study, Huddleston and Rolfe (1971) reported that the presence of simulator motion produced patterns of control response more closely related to those employed in flight. That is, using simulators without motion, experienced pilots were able to achieve acceptable levels of performance, but their patterns of control response showed that their performance was achieved using a strategy different from that used in a dynamic training environment. Research at the University of Illinois related to instrument display design found that the quality of the simulator motion involved affected pilot responses to display types differentially, with inappropriate banking motions interfering with command flight path tracking (Ince, Williges, & Roscoe, 1975).

Thus, numerous studies provide evidence that the presence of motion, i.e., movement of the platform upon which the simulator cockpit rests, does affect performance in the simulator. Not only can motion affect learning rates, but the performance of the pilot in the presence of motion may be different than it would be in the absence of motion. With motion, his simulator control responses to external forcing functions appear to be more rapid and accurate and more like responses used to control the aircraft in flight. While it cannot be concluded from these studies that simulator motion during training will enhance subsequent performance in the aircraft, they do suggest that simulator motion can affect the acquisition of skills in the simulator. These effects of motion upon performance in the simulator have been demonstrated under controlled experimental conditions that tend to make it unlikely that the noted differences in performance could be attributed solely to factors other than the presence of motion during simulator training.

The influence of platform motion is not necessarily beneficial, however. Excessive or inappropriate motion, e.g., high levels of simulated turbulence, could make learning less rapid if it were a factor in making the simulator more difficult to control. Likewise, motion that is out of synchronization with visual or other cues could interfere with simulator control if it made trainees ill or presented misinformation to them. For example, it has been reported that the simulator used in the Air Force ASPT study cited above has time lags in the motion system that make the performance of some maneuvers difficult (Hutton, Burke, Englehart, Wilson, Romaglia, & Schneider, 1976).

MANEUVER MOTION VS. DISTURBANCE MOTION

In discussing the influence of motion upon pilot performance in simulators, Gundry (1976a, 1976b) distinguishes between two kinds of motion cues and suggests that they might affect performance differentially. Maneuver motion is that motion that arises within the control loop and results from pilot-initiated changes in the motion of the aircraft in order to change its heading, altitude, or attitude. Disturbance motion, on the other hand, arises outside the control loop and results from turbulence or from failure of a component of the airframe, equipment or engines that causes an unexpected (to the pilot) motion of the aircraft. Matheny (1976) made a similar distinction in a study in which he identified aircraft motion as resulting from either external forcing functions or input into the aircraft controls.

The reason that platform motion can result in quicker, more accurate simulator control probably is that the disturbance component of that motion resulting from simulated turbulence or equipment failure can provide more rapid and relevant alerting cues about forces acting upon the aircraft than could be obtained from other cues sources. Maneuver motion does not fulfill an alerting function, because it results from pilot-initiated control movements. Research involving maneuver motion, Gundry states, indicates that this component of platform motion has little effect upon the control of an aircraft whose flight dynamics are stable. For unstable vehicles, however, the presence of maneuver motion will allow the pilot to maintain control even in flight regions where control by visual cues alone would be impossible. Thus, disturbance motion permits more rapid and accurate aircraft control under all flight conditons in which such motion is appropriate. Maneuver motion, however, improves aircraft control only when the aircraft is unstable.

In both the Jacobs and Roscoe and the Air Force ASPT studies cited above, emphasis was upon simulation of maneuver rather than disturbance motion. Since maneuver motion is pilot induced and the aircraft involved in these studies were quite stable, the most likely role of motion was to provide feedback to the pilot. If sufficient feedback were available from other sources such as the aircraft instruments or an extra-cockpit visual display, as likely was the case, the maneuver motion provided in these two studies could not be expected to have a large effect upon simulator training effectiveness, and probably would be ignored altogether by the trainees. Had these two studies examined the influence of disturbance motion resulting from factors outside the control loop, e.g., malfunctions, the results might have been different.

The evidence that disturbance motion may have a large effect upon pilot performance in the simulator and upon his subsequent performance in the aircraft should not be overlooked by personnel making decisions concerning the importance of platform motion in aircraft simulator training. The fact that the influence of such motion was not apparent in two recent transfer of training studies is probably attributable to the absence of a significant disturbance component to the motion involved in those studies. The maneuver motion that was present appears not to have been a significant factor in transfer of training for the undergraduate level trainee in the relatively stable aircraft involved in these studies.

PILOT PERCEPTIONS OF MANEUVER AND DISTURBANCE CUES

The author recently had occasion to examine four Air Force simulator training programs in which simulators with motion were employed. The simulators were the C-5A, the FB-111B, the F-4D and E, and the A-7E. Although the contribution of motion to the effectiveness of the combat crew training and continuation training activities in which these simulators are used has not been investigated empirically, the perceived value of the platform motion cues they provide was discussed with Air Force pilots and instructors who participate in that training. Many of these personnel held strong opinions concerning the probable value of motion. While those opinions were predominantly favorable, there were a few unfavorable ones as well. In all cases, whether favorable or unfavorable, the basis for the opinions expressed was explored by the investigator.

Favorable opinions were difficult to relate to specific aspects of motion simulation and in many cases were considered to be endorsements of the general idea that simulator motion is important because the aircraft moves. Those who were the most enthusiastic in their opinions favoring motion cited motion characteristics of the disturbance type as the primary basis for their positive views, i.e., motions associated with equipment failure, weapons release, buffet and turbulence. Very few pilots expressed strong positive feelings toward maneuver motion -- it contributed to realism but was not cited as specifically related to particular training goals.

The relatively few negative opinions expressed concerning motion were all strongly held, and they involved both maneuver and disturbance motion. In one simulator in which maneuver motion cues lagged noticeably behind instrument displays and tended to be jerky rather than smooth, the motion was viewed as annoying, and pilots using that particular device preferred to train with the motion system inoperative. Apparently, maneuver motion can have little positive value in most simulator training programs, but it can have a negative influence, at least upon pilot attitudes, if it is not representative of comparable motion in the aircraft, e.g., if it lags noticeably the pilot's control input or the cues provided by instruments or visual displays.

Most of the negative comments received during the interviews could be related to disturbance motion -- or, more precisely, to the absence of disturbance motion cues that the pilots knew to be characteristic of the aircraft simulated. Two examples of this situation were noted, one involving the A-7D simulator and the other involving the C-5A simulator.

A critical condition involving the A-7D aircraft is that labeled "Departure." It is a high angle of attack condition in which the aircraft yaws abruptly and enters an uncontrollable spin. The yaw in this case is a disturbance cue that alerts the pilot to the condition's onset. Training in recovery from the departure is considered of critical importance, but such training in the single-place aircraft is not included in A-7D training for reasons of flight safety. Attempts to provide the desired training in the A-7D simulator have been unsuccessful, reportedly because the yaw motion cues cannot be simulated in that device (it lacks the yaw motion axis).

The A-7D manufacturer has a research simulator, called LAMBS (for Large Amplitude Motion Base Simulator), in which the departure can be simulated with the yaw motion component. All Air Force A-7D pilots have undergone departure recovery training in LAMBS. Pilots who have previously experienced a departure in the aircraft have reported that its simulation in LAMBS is "realistic." Pilots who received training in LAMBS and subsequently experienced a departure in the aircraft credit the motion simulator training for the ease with which they were able to reestablish aircraft control, although such reports are purely subjective. In any event, the yaw disturbance cue provided by LAMBS is well received by Air Force A-7 pilots, whereas the absence of that cue in the Air Force simulator renders departure recovery training in it unacceptable.

One of the A-7D pilots interviewed had recently flown the Navy's A-7E simulator that has a six-axis motion system. That pilot expressed a highly favorable opinion concerning A-7D simulator training. While there are a number of differences in these two simulators and the manner in which they are used, the extent of motion simulation was singled out as an important difference between the two devices which, in the opinion of that particular pilot, influences training.

The C-5A simulator motion platform, like that of the A-7D, lacks the yaw axis, so the yaw disturbance motion associated with loss of an engine cannot be simulated. Pilots associated with C-5A training at Altus AFB cited this deficiency in the simulator as a negative factor in determining the effectiveness of simulator training for engine losses at low altitude. It was not cited as a factor in other training operations, including operations that involve yaw maneuver motion, however. Thus, where yaw could be considered a disturbance motion, it was perceived by these pilots to be needed for training; where it could be considered a maneuver motion, it was not perceived as important.

The C-5 simulator described above has a visual display, and the yaw of the aircraft associated with engine loss is reflected in the visual scene. The pilots indicated that the visual yaw cue alone was insufficient, in their opinion, when engine loss occurred during landing and takeoff maneuvers. They felt that pilots in the simulator responding to visual cues were much slower in initiating corrective action than they were in the aircraft where motion provides an early and more pronounced alert that a disturbance has occurred.

DISCUSSION

The influence of platform motion upon transfer of simulator training has not been clearly established by the data available at the present time. It has been demonstrated that motion can affect pilot performance in the simulator in ways that may make his performance in the simulator more like his performance in the aircraft, but it has not been shown that simulator motion enhances his subsequent performance in the aircraft. The two studies that have addressed the question of transfer directly did not support a conclusion that motion is needed. Likewise, there is no consensus among pilots as to the need for motion in simulator training.

The distinction between maneuver and disturbance motion is useful in attempting to understand both the prior research on motion and the reactions of pilots to the motion component of aircraft simulators. In the transfer of training studies in which motion did not appear to influence subsequent pilot performance, the motion involved was predominantly, if not exclusively, of the maneuver variety. On the other hand, disturbance motion was the predominant type of motion in studies in which changes in pilot performance were related to motion simulation. Thus, the results of both sets of studies can be accepted and attributed to the nature of the motion simulation involved in each. Disturbance motion is important, at least in training situations where disturbance cues can be related to specific training objectives and when the aircraft simulated is unstable or is particularly responsive to control input. Maneuver motion may be important also under some circumstances, but the evidence available at this time has not shown that it contributes to transfer of training in easy-to-fly aircraft with undergraduate level trainees.

More attention has been paid in the design of training simulators to maneuver motion than to disturbance motion. Emphasis has been upon providing in a simulator the motion cues associated with well-coordinated pilot control inputs, scaled down to the limits of travel and accelerations of the motion platform. Since most training and operational aircraft are relatively stable and easy to control in flight, this kind of motion simulation may be of very little potential value in training. It might be more beneficial from the training standpoint to provide the motion cues associated with disturbances to the aircraft not originated by the pilot, and then only at their initial onset values, so that the pilot can learn to respond specifically to such cues rather than learning to respond to visual or other cues that occur later in time.

Because the distinction between maneuver and disturbance motion has only recently been articulated, there has been little opportunity to examine systematically the influence of each upon simulator training effectiveness. Most prior training research on motion appears to have dealt primarily with maneuver motion, and maneuver motion appears reasonably well represented in the newer simulators, although time lags between pilot manipulation of aircraft controls and motion system responses have been a major problem in some of them. Disturbance motion has been less thoroughly investigated, and it is poorly or incompletely represented in many newer simulators. In fact, data on disturbance motion cues generally have not been developed and consequently are not available to motion system designers.

Additional research upon the role of disturbance motion in training is clearly needed. Emphasis in such research should be three-fold: (1) analysis of requirements for disturbance motion cues associated with specific simulator training objectives; (2) development of models for the representation of critical components of such motion in simulators; and (3) determination of the effects on transfer of training of the presence and absence of such motion.

Because of the continuing concern over the costs associated with motion simulation, future research on motion simulation should also examine the use of platform motion systems with limited axes of motion, g-suits and seats, and "seat shakers" to determine whether the disturbance cues found to be important in training can be represented adequately in such relatively low cost motion devices. In any event, future motion system designs should be responsive to requirements to provide specific movements which cue specific pilot responses rather than to provide motions which simply correspond to motions of the simulated aircraft.

The real issue in simulator motion system design is the relating of motion cues to required pilot responses. What are the motion cues to which a pilot responds during flight? What discriminations must he make among them? How do they affect his performance? How can they be provided economically?

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REFERENCES

DeBerg, O.H., McFarland, B.P., & Showalter, T.W. The Effect of Simulator Fidelity on Engine Failure Training in the KC-135 Aircraft. Paper presented at American Institute of Aeronautics and Astronautics Visual and Motion Simulation Conference, Dayton, Ohio, April 26-28, 1976.

Douvillier, J.G., Jr., Turner, H.L., McLean, J.D., & Heinle, D.R. Effects of Flight Simulator Motion on Pilots' Performance of Tracking Tasks. Technical Note NASA-TN-D-143. National Aeronautics and Space Administration, Washington, D.C., 1960.

Fedderson, W.E. The Role of Motion Information and Its Contribution to Simulation Validity. Technical Data Report No. D288-429-001. Bell Helicopter Company, Fort Worth, Tex., 1962.

Gundry, A.J. Thresholds to Roll Motion in a Flight Simulator. Paper presented at American Institute of Aeronautics and Astronautics Visual and Motion Simulation Conference, Dayton, Ohio, April 26-28, 1976.

Gundry, J. Man and Motion Cues. Third Flight Simulation Symposium Proceedings. Royal Aeronautical Society, London, April 1976.

Huddleston, H.F., & Rolfe, J.S. Behavioral Factors Influencing the Use of Flight Simulators for Training. Applied Ergonomics, 1971, 2.3, 141-148.

Hutton, D.P., Burke, D.K., Englehart, J.D., Wilson, J.M., Romaglia, F.J., & Schneider, A.J. Project No. 2235, Air-to-Ground Visual Simulation Demonstration Final Report, Volume 1. Aeronautical Systems Division, Simulator SPO, Wright-Patterson AFB, Ohio, October 1976.

Ince, F., Williges, R.C., & Roscoe, S.N. Aircraft Simulator Motion and the Order of Merit of Flight Attitude and Steering Guidance Displays. Human Factors, 1975, 17, 388-400.

Jacobs, R.S., & 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.

Matheny, W.G. Studies of Motion and Visual Interaction in Simulator Design and Application. Final Report LSI, AFOSR-FR-76-1. Life Sciences, Inc., Hurst, Tex., September 1976.

Perry, D.H., & Naish, J.M. Flight Simulation for Research. Journal of the Royal Aeronautical Society, 1964, 68, 645-662.

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

Woodruff, R.R. Full Mission Simulation in Undergraduate Pilot Training: An Exporatory Study. Technical Report AFHRL-TR-76-84. Air Force Human Resources Laboratory, Williams AFB, Ariz., December 1976.

ABOUT THE AUTHOR

DR. PAUL W. CARO is a Program Manager with the Seville Research Corporation, Pensacola, Florida. He previously was a Senior Staff Scientist with the Human Resources Research Organization, where he directed the HumRRO simulator training research program. He holds a Ph.D. in industrial psychology and psychometrics, is a Fellow of the American Psychological Association, is a member of the Human Factors Society and of Sigma Xi, and holds both airplane and helicopter pilot ratings.