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INCREMENTAL TRANSFER AND COST EFFECTIVENESS OF FLIGHT TRAINING SIMULATORS

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its use must be no greater than the cost of the flight time required to achieve the same learning in the airplane (Flexman, Roscoe, Williams, and Williges, 1972; Micheli, 1972; Povenmire and Roscoe, 1971; Williges, Roscoe, and Williges, 1973). Caro's saving of 53.5 airplane hours from 43 SFTS hours works out to a cumulative transfer effectiveness ratio of 1.24. Whenever the ratio of the cost of owning and operating a simulator to the cost of its counterpart airplane is less than its transfer effectiveness ratio, the simulator is cost effective.

To refine this determination, the use of the simulator should take into account its incremental cost effectiveness (Roscoe, 1971; 1972; Povenmire and Roscoe, 1973). Incremental cost effectiveness refers to the fact that successive increments of training in a simulator on any flight curriculum, or portion thereof, yield diminishing transfer to flight, as shown in Figure 2 (from Roscoe, 1971). At some point in training, the incremental transfer from the next hour in the simulator will save an increment of flight time so small that it would cost less than the next hour in the simulator. At this point, simulator training on this portion of the total curriculum becomes cost ineffective. Naturally, further use of the same simulator for other portions of the curriculum may continue to be cost effective. And, of course, it may be good training strategy to use a simulator beyond its cost-effective crossunder point for reasons of safety, bad flying weather, or meeting a rigid calendar schedule.

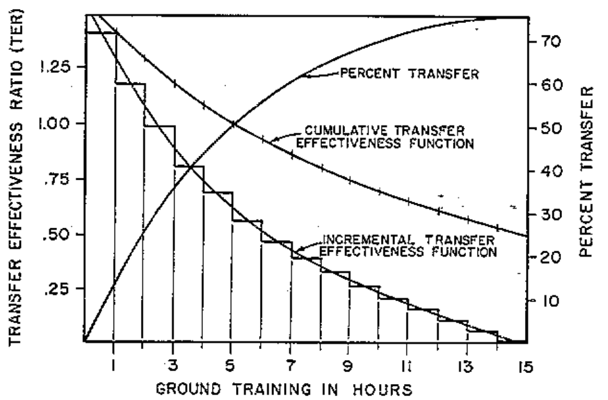

Figure 2. Relationship between transfer of training and incremental and cumulative transfer effectiveness in a hypothetical ten-hour flight curriculum.

A trainer's cost-effectiveness crossunder point can occur surprisingly early in a training curriculum. For example, the incremental transfer effectiveness ratio of the Singer-Link GAT-1 reaches 0.75, its approximate training cost ratio to the Cherokee PA-140 airplane, between its fourth and fifth hours of use in the Private Pilot course at the University of Illinois, as shown in Figure 3 (from Povenmire and Roscoe, 1973). The seven additional hours given, and legally substitutable for flight hours, save little additional flight time.

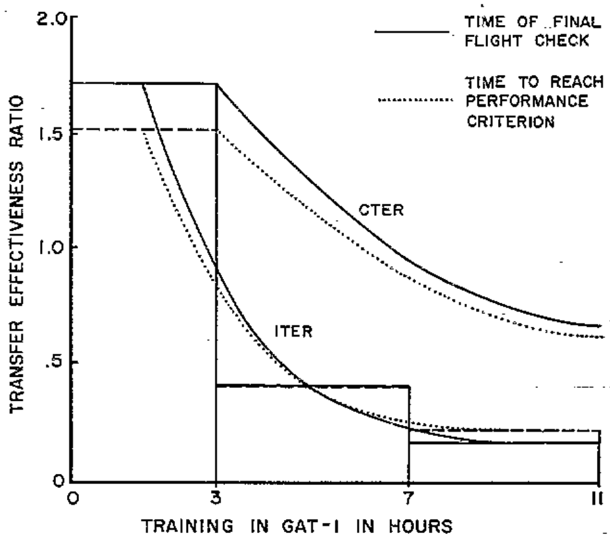

Figure 3. Empirical transfer effectiveness of the Singer-Link GAT-1 general aviation trainer in the Private Pilot course at the University of Illinois.

The fact that the SFTS is cost effective for a major portion of a flight curriculum, and the GAT-1 is not, does not support the conclusion that synthetic flight trainers have to be complex and costly to be transfer and cost effective. Quite to the contrary, the cost of the trainer must be considered in relation to its counterpart airplane, and such a simple device as a Link 1-CA-2, with a crude visual system, shown in Figure 4, consisting of a point light source, a sheet of aluminum with a slit cut out to represent a runway mounted on a Link Trainer crab, and a rear projection screen, prepared beginning students to land the North American T-6/SNJ airplane with a saving of more than 80 percent of the trials required by a control group (Payne, Dougherty, Hasler, Skeen, Brown, and Williams, 1954). The practical consequence of considering cost effectiveness in establishing specifications for a new training device is that relatively simple features that may yield slightly less transfer than vastly more complex and costly alternatives become the rational choice.

It is evident from the examples cited that the cost effectiveness of a synthetic training device depends, as the term implies, both on the cost of the device and on its transfer effectiveness. If the cost of owning and operating a simulator approaches the cost of its counterpart airplane, the cost-effective

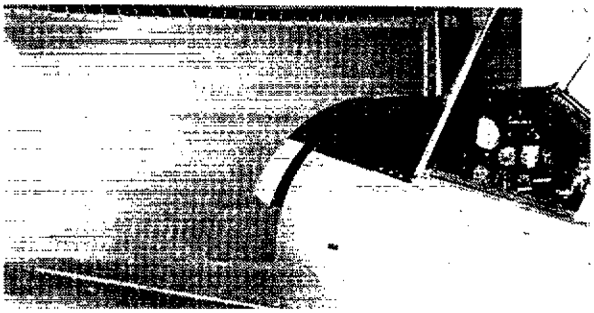

Figure 4. Link 1-CA-2 (T-6/SNJ) trainer with a point-light-source visual approach system.

crossunder point is reached whenever an hour spent in the simulator saves less than an hour in the airplane, that is, when the transfer effectiveness ratio (TER) drops below unity. However, if the cost of the simulator is low relative to the cost of the airplane, the simulator can be used profitably until its transfer effectiveness ratio drops to the point at which it equals a much lower cost ratio. Stated another way, one can profitably do more training in a cheap simulator with a high TER than in an expensive simulator with an even higher TER.

STATE OF THE SIMULATION ART

Although it would be unrealistic to specify flight simulator characteristics without taking into account the state of the simulation art, it would be both unrealistic and foolish to allow the state of the art to determine, by default, the simulator characteristics called for in a specification. Overly complex and costly simulators, like Mount Everest, are out there waiting to be specified, and the temptation to buy them is great.

Cockpit motion systems for simulators offer one of the widest ranges of choices in optional features, from no cockpit motion in Frasca trainers to huge, energy-hungry machines that throw cockpits and pilots through several feet of linear travel, accelerating them at several times the force of gravity. Because the most muscular systems developed to date cannot reproduce the accelerations of an airplane -- indeed, if one did it would be an airplane -- the quest continues for greater and greater motion system capability. But to double the duration of a given rate of change in acceleration requires eight times the distance and a 512 times larger building. Fortunately, evidence is mounting that the training and testing of pilots can be quite effective with far less costly motion systems (Koonce, 1974).

Simulation of the outside visual scene also affords a variety of alternatives ranging from relatively simple and inexpensive (Payne, Dougherty, Hasler, Skeen, Brown, and Williams, 1954) to extremely complex and costly (Smith, 1972), as it does in the case of motion systems. The difference is that none of the visual systems developed to date, even the most expensive, meets all requirements for all training purposes in an entirely satisfactory manner. The fact that no single visual system is suitable for teaching all of the perceptual-motor and decisional contact flight skills may be fortunate in that it may stimulate the experimental study of the minimum set of visual cues essential to high transfer of basic skills. To assess the adequacy of any visual simulation system for specific contact flight operations, it is first necessary to determine the visual cue requirements essential to teaching those operations.

TRAINING OBJECTIVES

Determination of static and dynamic visual cues and dynamic vehicle responses to be simulated should start with a categorical analysis of training objectives associated with the mission for which crews are to be trained. Training objectives may be classified under a set of behavioral categories useful in specifying associated simulator characteristics:

PROCEDURAL ACTIVITIES

- Communication management
- Navigation management
- Fuel and powerplant management
- Vehicle configuration management
- Sensor management
- Weapon management
- Battle damage management

DECISIONAL ACTIVITIES

- Navigation planning
- Threat or hazard assessment
- Target priority adjustment
- Mission priority adjustment
- Crew function adjustment

PERCEPTUAL-MOTOR ACTIVITIES

- Geographic orientation
- Vehicle control
- Target, threat, or hazard detection and identification
- Weapon delivery control
- Communication

Each of the training objectives for specific flight operations can be classified under one or more of these behavioral categories. Consideration of the types of training for which simulators have demonstrated capability reveals that, although they have proved most effective in the teaching of procedural skills and only slightly less effective for teaching of perceptual-motor skills (Flexman, Roscoe, Williams, and Williges, 1972), simulators have been virtually unused in the teaching of decisional skills.

The fact that simulators have been used little, if at all, in teaching decision-making skills is not surprising in view of the intangibility of such skills and the difficulty of defining good decision-making performance and judging when it has occurred. Nevertheless, few would argue that decisional activities of the types outlined distinguish the effective combat aircraft commander from the ineffective, and the cultivation of decisional skills is an instructional objective calling for situational training that may be carried out with safety only in a simulated tactical environment.

Further generalizations can be made concerning relationships between training objectives and simulator characteristics. In the Flexman, Roscoe, Williams, and Williges (1972) study of the anatomy of transfer it was concluded that:

> ...higher transfer occurs with procedural tasks than with psychomotor tasks because the former are less adversely affected by the imperfect simulation of such dynamic factors as physical motion, visual and kinesthetic cues, and control pressures.
>
> This is not to say that effective transfer of procedural tasks requires less fidelity of simulation than psychomotor tasks. To the contrary, the conclusion must be that procedural fidelity is more critical than dynamic fidelity in simulator design. Lack of procedural fidelity results in the transfer of incorrect responses, thereby yielding negative transfer to the performance of correct procedures in flight.

Another consideration in deciding upon which training objectives to assign to simulators is the relative rates of forgetting for various skill categories. In general, once perceptual-motor skills, such as *skating, hitting a baseball, or landing an airplane,* are learned, they are not quickly forgotten. Former pilots, given the opportunity, often land an airplane safely and smoothly after as long as 15, 20, or 25 years out of the cockpit. Procedural skills, on the other hand, are quickly forgotten. A World War II pilot who can still land his combat airplane safely is most unlikely to be able to start its engines. The generalization that procedural skills are forgotten more rapidly than perceptual-motor skills was confirmed experimentally by Mengelkoch, Adams, and Gainer (1958). The fact that infrequently used procedural skills can be retained and partially forgotten ones quickly restored in a simulator argues additionally for maintaining high procedural fidelity.

SELECTION OF TRAINING DEVICES

The purpose of synthetic flight training devices is not to train pilots to fly simulators; it is to train pilots to fly airplanes. It has been shown that, while cockpit motion makes a simulator easier to fly, thereby improving pilot performance in the simulator (Fedderson, 1961; Guercio and Wall, 1972; Ince, Williges, and Roscoe, 1973; Jacobs, Williges, and Roscoe, 1973; Roscoe, Denney, and Johnson, 1971) there is as yet no evidence that cockpit motion in a groundbased trainer improves pilot performance in an airplane. The issue is unresolved because there has not been an experiment designed to measure transfer directly in which either the degree or fidelity of cockpit motion was an independent experimental variable.

It has also been shown conclusively that the outcome of human engineering experiments, investigating the order of merit of flight displays, can yield quite different conclusions from experiments conducted in flight, depending upon the absence or presence and type of simulator cockpit motion (Ince, Williges, and Roscoe, 1973; Johnson and Roscoe, 1972; Matheny, Dougherty, and Willis, 1963; Roscoe and Williges, 1973). Although returns from successive increments in motion fidelity diminish rapidly, it is generally true that at least a modest motion system is required if human engineering experiments in simulators are to generalize accurately to performance in flight. So, it would indeed be surprising if the degree and fidelity of cockpit motion turned out not to make a difference in training effectiveness, but the fact is that what difference they make, positive or negative, is not well understood.

The first experiment bearing directly upon the transfer from a simulator to an airplane as a function of the kind of simulator motion was recently conducted for an entirely different purpose; the 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 24 instrument rated pilots each were tested on Day 1 and Day 2 in the simulator and then on Day 3 in the airplane, as shown in Figure 5.

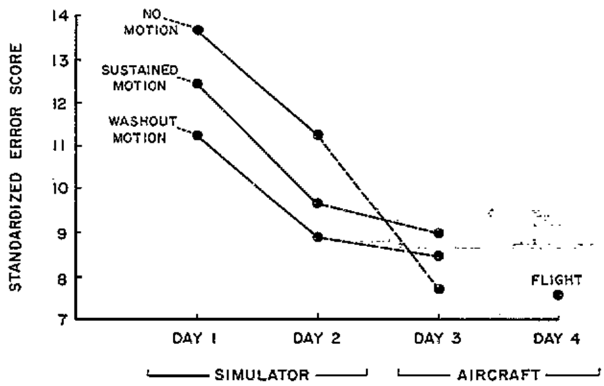

Figure 5. Transfer of refreshment of instrument flight skills in the Singer-Link GAT-2 general aviation trainer to flight check performances in the Piper Aztec light-twin airplane as a function of presence and type of simulator cockpit motion.

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.

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. 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 reliability disproportionate improvement by the group tested with no cockpit motion in the simulator strongly indicates differential transfer. Apparently, pilots trained in moving simulator cockpits learn to depend upon acceleration cues, which they must learn not to depend on in the air because much airplane motion occurs at subliminal acceleration levels.

The first direct experimental investigation of this question was recently undertaken at the University of Illinois (Jacobs and Roscoe, in progress). Transfer of training from a modified Link GAT-2 general aviation trainer to a light general aviation aircraft, using a flight syllabus that samples procedural, decisional, and perceptual-motor activities, is being measured as a function of three different cockpit motion conditions. These include no motion, as a reference condition, normal washout banking and pitching motion, and a hybrid washout motion condition in which the direction of roll is randomly reversed 50 percent of the time as the cockpit passes through the neutral position, thereby compounding the conflict between visual and vestibular cues. In the transfer control condition, all training is given in flight.

The hybrid random-direction washout condition is included to investigate the effect of separating directing cues from alerting cues. Suprathreshold accelerations provide both types of information, and it has been speculated by many that it is the alerting function that makes moving-cockpit simulators easier to fly. By retaining alerting cues from the onset of motion but making the direction of accleration cues undependable, the pilot may be taught to depend more completely on flight instruments as he must learn to do in the air.

In deciding upon the fidelity of extra-cockpit visual simulation that is optimum for contact flight training, one enjoys little more comfort in experimental fact. Perhaps the most cost and energy effective contact flight trainer will continue to be a light airplane for years to come. Certainly, any synthetic flight trainer designed to teach the basic contact flight skills involved in takeoff and landing should be relatively inexpensive because there are relatively few flight hours in relatively low cost aircraft to be saved.

As the cost of flying the counterpart aircraft increases, more can be spent efficiently for simulation. An hour in a Boeing 747 simulator costs a small fraction (about $400) of an hour in the airplane (as much as $4000). Consequently, the airlines have found it economical and convenient, and of course safer, to do more and more of their training and testing in simulators because the availability and cost of operational aircraft argue against their use for these purposes. In their case, moderately complex and costly extra-cockpit visual systems are both cost and energy effective.

In addition, a disproportionate premium can be placed justifiably on saving pre-solo and transitional flight hours, because these training phases are disproportionately dangerous and costly in terms of damaged aircraft. Furthermore, the refinement of ground-referenced flight skills does not end at first solo or upon transitioning to a new aircraft; continued use of contact flight simulators can be justified for teaching students to cope with severe crosswinds, gustiness, and wake turbulence near the ground, and certainly for air-to-air and air-to-ground combat.

Analysis of pilot training objectives indicates that the most difficult problem areas are associated with cognitive skills rather than motor skills. Not only are procedural activities primarily cognitive, but they tend to be mission specific, or at least specific to the particular aircraft and operational environment, whereas perceptual-motor flying skills tend to generalize to various aircraft and missions. Although flight control requires a fine touch and sustained attention, it involves the same basic coordinated flying skills from airplane to airplane.

A cornerstone of simulator technology upon which effective cognitive training rests is procedural fidelity. Although it is logistically difficult to keep changes in simulator cockpits in pace with changes in operational aircraft cockpits, the consequences of not doing so are tutorially disasterous. "Teaching around" differences in switching controls and associated procedural operations between the simulator and its counterpart aircraft is a challenge to the most dedicated flight instructor and quite beyond the aspiration level of many.

Although the foregoing observations do not constitute a formula for specifying characteristics of synthetic flight trainers, they do offer a basis for evaluating whether or not any existing or proposed device is readily addressable to specific training problems. In making such a judgment, it is imperative that the effectiveness of the device be expressed as a function of its cost.

REPRISE

It's a Barnum and Bailey world,
Just as phoney as it can be,
But it wouldn't be make believe
If you'd believe in me.

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