OPTIMIZING SIMULATOR-AIRCRAFT TRAINING MIXES*

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ABSTRACT

Under the assumptions that (1) as simulator training increases, required aircraft training decreases to some non-negative minimum and that (2) at any point, the rate at which required aircraft training decreases is a fixed proportion of the difference between present required training and the minimum required training achievable, the function relating x, the simulation training received, with y, the subsequent training required in the actual aircraft to attain criterion, will be of the form $y = ae^{-bx} + c$. This formulation has tremendous utility in allowing the training analyst to calculate the most cost effective mixes of simulator and aircraft training. This approach was applied in the U.S. Army's acceptance tests of the AH-1 flight simulator (AH1FS). Non-linear regression analysis of data collected on some 30 individual maneuvers indicates the methodology is viable. A straightforward methodology for incorporating these results into analysis of the combined cost and training effectiveness of the AH1FS and similar training devices is presented.

Implicit in the acquisition of any simulation training system is the assumption that training objectives are more economically attained through a mix of simulation and hands-on training than through hands-on training alone. This was the concept guiding the U.S. Army when in 1967 the basic requirements and projections for a Synthetic Flight Training System (SFTS) were first elaborated. Faced on the one hand by rapidly increasing training and operating costs and encouraged on the other by advances being made in training simulator technology, the Army embarked on a long-range SFTS development program, developing first the UH-1 Iroquois (Huey) instrument flight simulator and then the CH-47 Chinook visual flight simulator. The latest addition to the SFTS program is the AH-1 Cobra visual flight and weapons system simulator (AH1FS).

This paper reports in detail a novel methodology used in determining the training effectiveness of the AH1FS as a training medium for transitioning rated rotary wing aviators to the AH-1 aircraft. The report is presented in three general sections. The first describes the derivation of the methodology; the second presents the results of applying this methodology in testing the AH1FS; and the third describes how the data obtained is to be used in determining optimal mixes of simulator and aircraft training.

METHODOLOGY FORMULATION

Training Effectiveness

As indicated above, the motive driving training simulator development is economy in training. The economy achieved is, of course, determined by the cost and the effectiveness of a unit of simulator training relative to the cost and effectiveness of a unit of (in the present case) aircraft training. With past simulators, the cost differential between simulator and aircraft training has been so great that a marginally effective simulator might be used to realize overall training savings. However, as simulators have grown more complex and expensive to operate, the differential has shrunk to the point that precise quantitative determination of training effectiveness is becoming a major step in U.S. Army simulator testing and acceptance procedures.

Training effectiveness can be viewed and defined in many ways, but as Roscoe (1) points out, traditional measures of effectiveness fail to take into consideration costs associated with pre-training or simulator training. Roscoe has proposed the cumulative transfer effectiveness ratio (CTER) as an alternative with more utility for the training psychologist. The CTER is defined as

$$CTER = (x_0 - y_i) / x_i,$$

where x_i is training received in a simulator, y_i is training required in the aircraft after x_i simulator training, and x_0 is training that would be required in the aircraft were no simulator available. The ratio compares training savings in the aircraft as a function of amount of simulator training; a CTER of .75 would indicate that for some x_i units of simulator training, each unit is equivalent to .75 unit of aircraft training. The CTER has great utility to the training psychologist as a measure of training effectiveness and was quite successfully employed in Holman's (2) evaluation of the CH-47 flight simulator.

But, as Roscoe points out, the CTER is not a constant but is very much a decreasing function of the value of x_i. In fact, if $x_0 - y_i \geq 0$, it can be seen that

$$\lim_{x_i \to \infty} \left[\frac{x_0 - y_i}{x_i}\right] = 0. \qquad (1)$$

Thus, it is the case that each empirically established CTER will be valid only for some arbitrarily small neighborhood around its particular x_i.

*The views, opinions, and/or findings contained in this report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation.

From the training psychologist's point of view, an ideal measure of training effectiveness should convey the same information as does the CTER but should also allow computation of training effectiveness for all x_i. This could be accomplished by regressing CTER on various experimental values of x, but a simpler and more direct approach is to regress y on x. That is, find a suitable prediction rule or function which can be used to relate the independent variable of x relatively inexpensive units of flight simulator training with the dependent variable of y relatively expensive units of aircraft training required to attain the training objective. Once this training effectiveness function relating units of simulator training with units of subsequently required aircraft training is determined, the training psychologist can apply to the function the respective cost factors associated with the two training media and then minimize the resulting total cost function.

Derivation of Model

Now that the potential utility of such a concept of training effectiveness has been illustrated, how can the function relating x and y be characterized? In this section a model relating simulator and aircraft training will be developed, both intuitively and theoretically, and evaluated against extant empirical data.

At the intuitive level, one would expect the function sought to exhibit several characteristics. At $x = 0$, i.e., no simulator training, y is equal to the CTER's y_0, the amount of aircraft training required when a simulator is not used. As x increases, y should decrease; that is, as amount of simulator training increases, amount of subsequent required aircraft training should decrease. However, the rate of decrease should not be constant; from the nature of the CTER, it is known that the pay-back from investing more units of training in the simulator becomes less and less. That is, although the rate of change of y with increasing x is negative, the rate of change approaches zero, resulting in some asymptotic minimum non-negative value of y which will be denoted by c. The value of c represents the amount of aircraft training that must be done to attain the training objective regardless of the amount of simulator training administered. For the training effectiveness model, c is conceptually representative of those "task elements" which are not trained by simulation but must be learned in the aircraft. For those cases in which all task elements are trained in the simulator, c would be equal to zero. An intuitive graph of the function is shown at Figure 1.

Consider y as it ranges between a maximum at y_0 and a minimum at $y = c$. The quantity $y_0 - c$ can be considered as representative of the potential aircraft savings that can be realized by using the simulator. Assume that, as x increases, the rate at which y decreases (and savings accrue) is a constant proportion of $y - c$. This can be represented mathematically as the linear differential equation

$$\frac{d(y - c)}{dx} = -b(y - c), \qquad (2)$$

where b is the proportional constant. Substituting g for $y - c$, the equation becomes

$$\frac{d(g)}{dx} = -b(g)$$

which has general solution

$$g = ae^{-bx}, \qquad (3)$$

where a is an arbitrary constant. Replacing g by $y - c$ yields

$$y - c = ae^{-bx} \qquad (4)$$

$$y = ae^{-bx} + c.$$

Equation (4) is then a good theoretical candidate for the function the training psychologist seeks in relating simulator training with aircraft training.

Other than the study reported here, little quantitative data for evaluation of the model are to be found in the literature; most training effectiveness studies, being oriented toward transfer of training proportions or toward CTERs, have not systematically varied x, the amount of simulator training given. A notable exception occurs in a study conducted by Povenmire and Roscoe (3). In evaluating a generic aircraft simulator, Povenmire and Roscoe gave general aviation students up to 11 hours instruction in the simulator followed by training to criterion in the aircraft. Data from their Table 3 are plotted in Figure 2. The curve in Figure 2 is a rough fit of equation 4 to their data. For this fit, the proportional constant b has an approximate magnitude of .397, which is well within its theoretically expected range.

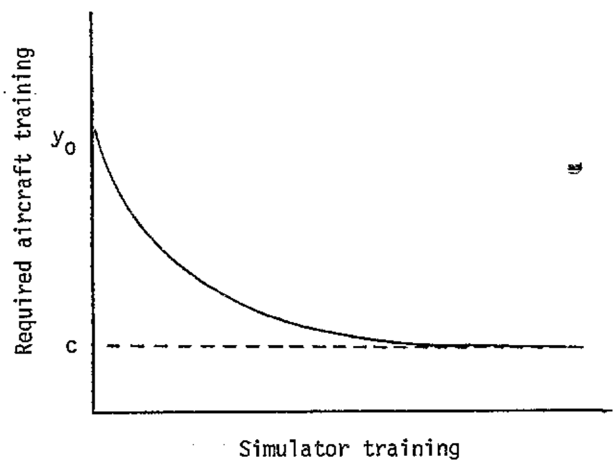


Figure 1. Hypothetical relation between antecedent simulator training and subsequent required aircraft training.

Level of Analysis

To this point, no mention has been made of the specific level at which the proposed analysis is to be made. In the case of the Povenmire and Roscoe data, the analysis was made at the level of the entire curriculum: data were collected in terms of the total time students were trained in the simulator or in the aircraft. Thus, any measure of effectiveness derived is a measure of the training device as a whole. However, it may be that the device is more effective in one area of training than in another. The training analyst requires information as to the device's areas of greatest effectiveness in order that training curricula may be developed which capitalize on the simulator's training strengths. One way this information may be obtained is by evaluating the simulator at the level of individual training maneuvers. In using this level of approach in the evaluation of the U.S. Army's CH-47 helicopter flight simulator (CH47FS), Holman (2) found that, although the CH47FS is effective overall (.82 average CTER), CTERs for individual maneuvers ranged from zero to 2.80.

In view of this finding, and since the AH1FS has incorporated in it most of the CH47FS's technical design features, it was decided to evaluate the AH1FS at the level of individual maneuvers. The general approach taken was to administer regular flight students varying amounts of AH1FS training in each maneuver and then to observe the additional amounts of aircraft training required for them to attain proficiency.

PROCEDURE

Subjects

Instructors. Instructor pilots (IPs) then currently assigned to the Attack/Aeroscout Branch of Hanchey Division of the Department of Flight Training of the Directorate of Training of the U.S. Army Aviation Center (USAAVNC) served as flight instructors. The IPs were all experienced aviators, qualified in the AH-1 aircraft, and graduates of the Attack/Aeroscout Branch's Methods of Instruction course.

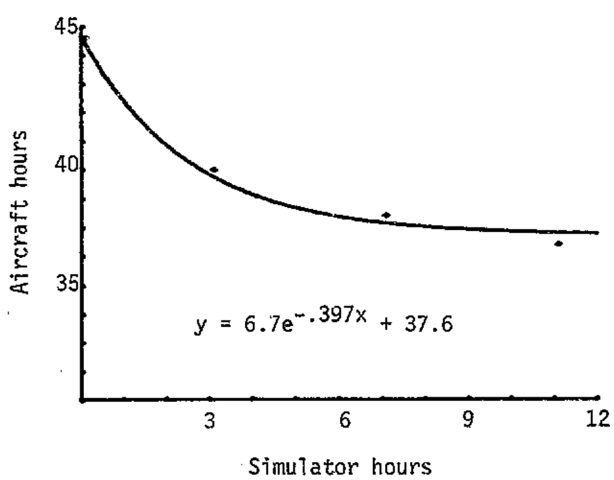


Figure 2. Fit of model to Povenmire & Roscoe results.

Students. Experimental subjects (Ss) were rated Army rotary wing aviators selected from regular USAAVNC AH-1 transition classes in residence during April-August 1979. Some Ss received all their training in the AH-1 aircraft; others received AH1FS training followed by training in the aircraft.

Administrative constraints and scheduled daily AH1FS availability restricted the experimental sample size per class to 8 for aircraft training only and to 6 for simulator plus aircraft training. Only those commissioned officer students in the grade of captain or below and those warrant officer students in the grade CW3 or below were considered. The remaining selection criterion was number of total flight hours: those Ss with the lowest number of total flight hours were selected.

Apparatus

The AH1FS is a high-technology training device which simulates the AH-1 aircraft cockpit and instrumentation, aircraft motion and vibration, aircraft power plant and weapons noise, and out-the-window view. It is designed to afford training in visual contact flight, instrument flight, and weapons delivery techniques.

Preliminary Activities

Instructor training. Prior to start of the study proper, 3 experienced IPs, selected by the Scout/Attack Branch, received a 5-day "instructor-operator" course conducted by the simulator manufacturer. Primary topics were simulator operating procedures and simulator-specific instructional strategies. At the end of training, all three were judged as qualified AH1FS instructor-operators by both the manufacturer and the Army simulator test-acceptance pilot assigned to the project.

Data specifications. As indicated above, it was decided the level of analysis for the study would be that of the individual maneuver. Prior to the study's start, the suite of maneuvers then taught by the Scout/Attack Branch was identified. Following the general format developed by Holman (2), a booklet allowing for collecting data on up to four repetitions of each maneuver daily was developed. Table 2 contains a list of the maneuvers evaluated. Data collected on any one maneuver repetition included the number of training minutes spent in performing the repetition and a rating of the trainee's overall performance on the repetition. The scale used for the overall rating is shown in Figure 3.

All Scout/Attack Branch AH-1 IPs were instructed in the use of the data collection booklet and rating scale. Prior to commencement of the test proper, each instructor pilot had satisfactorily demonstrated use of the booklet by recording data from one of his regular transition course students.

AH1FS training amount determination. As indicated previously, the overall test methodology was to involve observing the amount of aircraft training required after various amounts of AH1FS training. Subsequent regression analysis of these data would require that the amounts of AH1FS training selected be independent of the trainees. Specifi-

Rating	Description
0	Demonstration by IP; no evaluation.
1	IP immediately had to take back control of the aircraft.
2	Performance deteriorated until IP was finally obliged to take back control of aircraft.
3	Student required considerable verbal assistance.
4	Some parameters within course limits; verbal correction from IP required.
5	Some verbal assistance required; less than half of parameters within course limits.
6	Minimal verbal assistance; more than one-half parameters within course limits.
7	Few parameters outside course limits; student corrected performance with coaching; still lacks good control touch.
8	All parameters within course limits; work needed on control touch.
9	Outstanding; no perceptible deviations from standards; SIP-level performance.

Figure 3. Maneuver rating scale.

cally, in such a regression analysis, Ss cannot have been trained to some level of proficiency; having done so, in effect, would have allowed each trainee to determine his own amount of AH1FS training and thereby violate the underlying assumption of independent assignment of training amounts. Thus it was determined that for each maneuver, Ss would each receive one of 3 pre-specified numbers of training repetitions in the AH1FS.

Inspection of Figure 1 indicates that the magnitudes of the 3 values chosen can be critical to the analysis. If all 3 independent variable values are chosen too large, then the resulting dependent variable values will all lie in the asymptotic portion of the curve and inferences about the descending portion of the curve may lack precision. On the other hand, if all 3 values are chosen too small, then the dependent variable values will all lie in the descending portion of the curve and inferences about the magnitude of the asymptote may lack precision. It can be seen that, ideally, independent variable values for each maneuver should be chosen such that resultant dependent variable values fall both in the descending and in the asymptotic portions of the curve.

Since the AH1FS was a new piece of equipment with no quantitative training effectiveness history, estimation of each maneuver's ideal amounts of training was, of necessity, based on several outside considerations. First, Scout/ Attack Branch IPs were asked to estimate the average number of maneuver repetitions the average AH-1 transition course student requires to reach institutional proficiency in the aircraft. Also, for maneuvers common to both the AH-1 and CH-47, data collected in the CH-47 flight simulator evaluation (2) were examined. Then based on these data, on their sizable experience as IPs, and on their perceived effectiveness of the AH1FS as a training device, the AH1FS instructor pilots and the simulator project test pilot individually and then collectively estimated for each maneuver three amounts of AH1FS training that should capture both the descending and the asymptotic portions of the generic curve shown in Figure 1.

Method

Due to various operational considerations, it was decided that Ss trained in the AH1FS would receive at least some training on all maneuvers in the simulator; data for each maneuver for the condition "no AH1FS training" were to be collected from Ss receiving all their training in the AH-1 aircraft. The normal AH-1 transition course as taught at USAAVNC had a maximum 1f 12 students and was of 4 week's duration, with a new class starting every 2 weeks. Ss to receive AH1FS training were selected from every other class; Ss to receive aircraft training only were selected from each class as feasible.

AH1FS training. Simulator-trained Ss followed the same general daily training routine as their aircraft-trained counterparts. The standard daily routine allowed for two instructors each to train 3 students for 1.5 hours apiece. Except for utilization of simulator-specific features such as "freeze," "play-back," and demonstration tapes, the AH1FS instructor pilots followed the same standard curriculum that was being used in the aircraft. The only major departure from the standard was in progression through the curriculum: where individual training progression was profi-

TABLE 1. STUDENT GENERAL CHARACTERISTICS

	Low	Average	High
1. Age	21	27	32
2. Total RW flight hours	160	594	2500
3. Total RW flight hours in last 6 months	0	95	190
4. Years since graduation from RW flight school	0	2.3	9

ciency-based in the aircraft, in the AH1FS it was based on completion of the pre-specified numbers of training iterations of each maneuver. For each S for each maneuver, the pre-specified level of training to be received was assigned randomly under the constraint that overall equal numbers of Ss received each of the 3 levels. After completion of AH1FS training, Ss began training in the aircraft.

Aircraft training. The AH1FS-trained S's first exposure to the AH-1 aircraft was a diagnostic checkride administered by a Standardization Instructor Pilot from the USAAVNC Directorate of Evaluation/Standardization. Based on the results of this checkride, the S's AH1FS instructor continued training him to proficiency in the AH-1 aircraft. When his instructor considered him proficient in the aircraft, the student was given an end of course aircraft checkride by another IP and released from training.

Those Ss not receiving training in the AH1FS received normal instruction and training in the aircraft.

RESULTS

Subjects

During the conduct of the study, the Scout/Attack Branch experienced unforseen shortages of both personnel and aircraft. The effects upon the study were two-fold: new instructor pilots with no experience with the data collection booklet entered the training system, and students trained in the aircraft many times received aircraft instruction from more than one instructor pilot. As new instructor pilots began carrying students, they were instructed in the use of the data collection booklet and began collecting data on their students. A new instructor pilot's first students' data were discarded. Also, any student receiving instruction from more than two instructor pilots (not counting the checkride IPs) during the four-week transition course was discarded from the analysis.

Students. A total of 22 Ss began training in the AH1FS. With the exception of one who was grounded for medical reasons unrelated to the test, all successfully completed AH-1 flight training. A total of 25 Ss entered the study to receive aircraft training only. Due to the above-mentioned problems with instructor availability, data from all but 14 of these Ss were discarded. Descriptive data of these 35 Ss is shown in Table 1.

Maneuvers

Missing data. If in simulator training a S received as many as 2 fewer or as many as 2 more training repetitions for a maneuver than had been assigned him, his data for that maneuver were discarded. This condition generally arose due to abnormally low simulator availability or through oversight on the part of the simulator IPs. Also, for some maneuvers, some Ss trained in the aircraft alone were neither trained to criterion (as defined below) nor tested on that maneuver on the end-of-course checkride. Data in these cases were also discarded. Thus, in most of the results given below, data for a maneuver are based on a sample of less than 35.

Over-training. It was discovered early in the study that, although the AH-1 transition course was (within the limits of its 4-week duration) self-paced and proficiency based, over-training unavoidably occurred on some maneuvers. For example, since most training involving takeoffs and landings or autorotations involved flying a traffic pattern around the training stagefield, students in the aircraft routinely received considerable over-training in flying traffic patterns. Thus, after consulting with all the instructors involved, it was decided that a student would, for purposes of the study, be considered to have attained proficiency on a maneuver in the aircraft when for 3 consecutive training repetitions he had been rated at least a "7" (see Fig. 3) and, of course, provided he was rated at least a "7" on the maneuver on the end-of-course checkride. All aircraft training subsequent to the three "7s" criterion was considered over-training and not included in the analysis below.

Presence of trend. As a general indicant of degree of overall relationship between amount of AH1FS training and subsequent required AH-1 aircraft training, eta-squared was computed for the data for each maneuver. The values found, which can for this sample of Ss be interpreted as the proportion of variance accounted for by knowledge of amount of AH1FS training, are entered in Table 2.

Regression analysis. For each maneuver, the data described above were fit to the function $f(x) = ae^{-bx} + c$ using the SPSS sub-program NON-LINEAR (4). Marquardt's method was used to obtain

TABLE 2. MANEUVER RESULTS

Maneuver	N	η^2	a	b	c	df	F-ratio	Residual
			Parameter Estimates					
Cockpit procedures	34	.82	6.41	1.878	2.65	1,30	3.711	1.39
Takeoff to hover	32	.56	10.24	3979	3.68	1,28	.074	4.00
Hover flight	33	.59	11.87	.368	3.35	1,29	.033	4.87
Hover landing	35	.71	10.23	.390	2.98	1,31	.029	3.14
Hi-speed flight	33	.60	6.89	1.129	3.03	1,29	.317	2.71
Normal takeoff	33	.35	13.86	.161	2.57	1,29	.198	4.53
Normal approach	33	.79	9.96	.131	2.02	1,29	.696	2.06
Maximum power takeoff	29	.63	4.56	.400	1.16	1,25	.061	1.59
Steep approach	30	.44	2.88	.724	1.58	1,26	1.243	1.60
Running landing	23	.64	1.95	.436	.78	1,19	1.180	.64
Traffic pattern	33	.64	16.36	.608	4.57	1,29	.024	6.05
Hydraulics failure	27	.72	8.18	.179	1.54	1,23	.036	2.84
Forced landing, power recovery	27	.53	8.35	1.5×10^6	3.15	1,23	.038	3.92
Autorotation to touchdown	31	.53	8.34	5.1×10^{35}	4.44	1,27	.099	3.85
Autorotation with turn	33	.29	4.57	.395	3.37	1,29	.477	3.47
Autorotation, power termination	19	.05	.50	·17.20	2.00	1,15	.809	1.08
Hovering autorotation	32	.49	3.59	1.7×10^{54}	2.06	1,28	1.991	1.95
Left anti-torque failure	28	.61	8.52	.316	1.55	1,24	.418	3.38
Right anti-torque failure	27	.53	6.99	.548	1.51	1,23	1.561	2.90
Low level autorotation	28	.43	3.57	2.5×10^5	3.20	1,24	.928	2.16
Low level high speed autorotation	26	.24	1.62	1743	2.54	1,22	1.330	1.60
Hover out of ground effect	25	.56	1.90	2.2×10^5	1.25	1,21	3.654	1.04
Terrain flight takeoff	23	.48	3.73	1.388	.27	1,19	.046	1.67
Terrain flight	26	.44	3.81	1.149	.55	1,22	.214	1.96
Terrain flight approach	22	.36	3.29	17.16	1.00	1,18	.229	2.39
SCAS off operations	22	.09	.10	1.555	2.16	1,18	1.980	1.06
Weapons cockpit procedures	25	.49	4.54	478.7	.38	1,21	.651	2.61
2.75" FFAR ballistic correction	27	.46	5.16	5.2×10^{13}	.07	1,23	.020	2.77
FFAR firing	28	.49	5.32	4.2×10^{43}	.07	1,24	.012	2.69
20mm ballistic correction	27	.74	2.16	3180	.07	1,23	.147	.65
20mm firing	24	.65	2.38	1.6×10^7	.08	1,20	.102	.86

parameter estimates; iteration ceased when the largest relative change among the 3 parameters became less than 1.5×10^{-8}.

Best fit parameters for each maneuver are entered in Table 2. Also shown for each is its RMS residual and an F-ratio of goodness-of-fit (5). In the interest of conserving space, graphic results for only 4 maneuvers are shown; these appear in Figures 4-7 and are discussed in more detail below.

DISCUSSION

As indicated at the outset, one of the major objectives of the test of the AH1FS was to evaluate a methodology for quantifying training and cost effectiveness of simulators. In this section, the success of the methodology in capturing the simulator's effectiveness will be scrutinized, and then a straightforward application of the results to curriculum development will be outlined.

Training Effectiveness

The overall data indicate that the AH1FS is an effective device in training nearly all maneuvers investigated. This is evidenced by the general reduction in required aircraft training for each maneuver following simulator training (i.e., for all maneuvers, the rate parameter b indicates a decreasing function of x). But the specific results of particular interest are those pertaining to the accuracy of the transfer model and the success of the methodology in obtaining usable input for efficient curriculum design.

Presence of trends. The initial analysis of the data indicates there is indeed, in most cases, a functional relationship to be found between

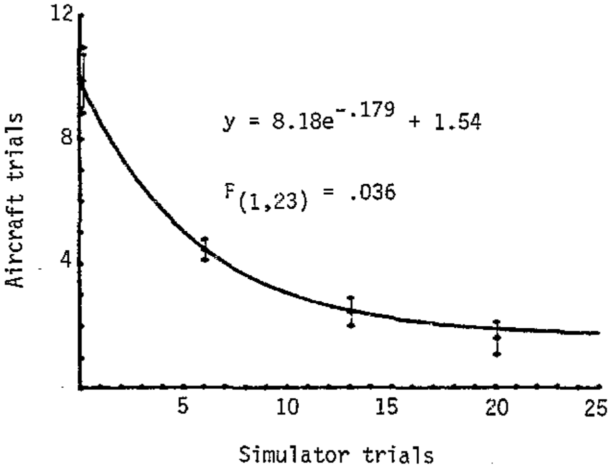


Figure 4. Hydraulics failure.

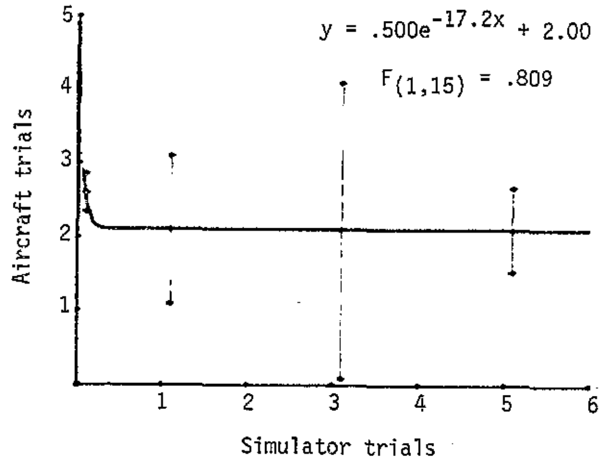


Figure 5. Autorotation, termination with power.

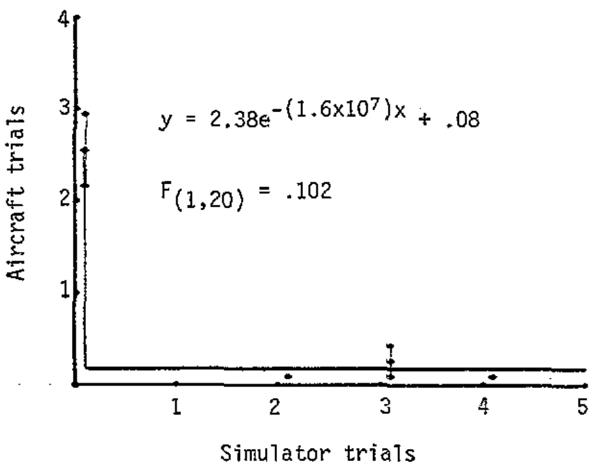


Figure 6. 20mm firing.

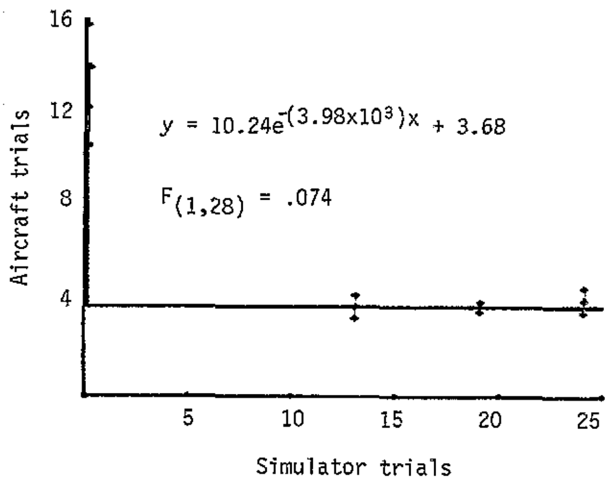


Figure 7. Takeoff to a hover.

amount of simulator training and amount of subsequent aircraft training. Table 2 shows that for this sample, except for "autorotation, termination with power" and "SCAS off operations," between 25 and 80 percent of the variance in aircraft training amounts can be accounted for by amount of simulator training, depending on the maneuver. Hence, there is some motivation for attempting to fit a model to the data.

Goodness-of-fit. In all cases, the model fits the data for each maneuver with values for a and c within their theoretically expected ranges. (Problems with values for b will be discussed below.) However, it is difficult to judge the absolute goodness of fit of any model. For the curve-fitting routine used with most, parameter values are selected that maximize the precision with which the dependent variable can be predicted from the independent variable. Of course, the predicted values and their corresponding observed dependent variable values will differ; the magnitude of the variance of this difference is a general indicant of goodness of fit: small variance results from a good fit. However, it is also the case that for a given level of the independent variable, there will be variance in the resultant levels of dependent variable observed. If this variance is conceptualized as the "noise" inherent in the data, then at least that much "noise" is also to be expected in the precision of prediction using the best fit parameters. To the extent the variance of the fit's precision exceeds that of the dependent variable observed values, the fit can be regarded as bad. Conversely, a good fit *will yield a precision variance not significantly* larger than the dependent variable variance. The F-ratios in Table 2 compare these variances; none is significant at the α = .05 level. But this is somewhat to be expected: the experimental design could economically allow sampling at only 4 values of the independent value, and the model is left to fit the 4 resulting mean dependent variable values with 3 free parameters. It should be pointed out that a "good" fit is not necessarily "the" fit; there are other models and theoretical functions that would fit the data just as well or even better. For example, Cronholm (6) has pointed out that, if both simulator and aircraft learning curves are assumed exponential with rate parameters g and h, respectively, then a very good case can be made for a function of the form

$$y = (h^{-1}) \ln (ae^{-gx} + c).$$

Thus it may only be concluded that there is no cogent reason for rejecting as a viable heuristic the model under consideration.

Individual maneuvers. The maneuver "best fit" curves obtained can be arbitrarily placed in four categories represented by Figures 4-7.

The first category, of which Figure 4, "hydraulics failure," is an example, consists of those "well-behaved" curves for which a is large relative to c and the rate parameter b is not too precipitous. As inspection of Table 2 parameter values shows, this was the case with the majority of the maneuvers evaluated.

A second category, represented by Figure 5, "autorotation, termination with power," consists of those maneuvers for which a is small relative to c. This relationship is indicative of poor transfer to the aircraft and occurred with only one other task, "SCAS-off operations."

A third category, represented by Figure 6, "20mm firing," is characterized by values of c close to zero. A negligible value of c can, as previously discussed, be considered indicative that complete transfer from simulator to aircraft was attained. The five gunnery tasks and "terrain flight take-off" fall into this category.

The last category is represented by Figure 7, "take-off to a hover." As mentioned previously, ideally, experimental values of the independent variable should be chosen such that not all three yield dependent variable values falling in the asymptotic portion of the curve. Despite the attempts made to avoid them, such choices were evidently made in the cases of "take-off to a hover," "forced landing with power recovery," "touch-down autorotation," "hovering autorotation," "low level autorotation," "low level high speed autorotation," and "hover out of ground effect."

Consider Figure 7. Based on various considerations, it was decided to sample the independent variable at levels of 0, 13, 19, and 24 repetitions. Inspection of Figure 7's best fit curve indicates that 13 or more AH1FS training repetitions yield results in the asymptotic area of the function. The reiterative curve-fitting routine used, in effect, fit these asymptotic data with a line parallel to the abscissa.* Although it may be that one training repetition in the AH1FS is efficacious to the extent indicated by the curve, it is very much more likely that, had an independent variable value in the range of 3-7 repetitions been chosen, a much less acute function would have been obtained.

Integration of Cost with Training Effectiveness

Since costing procedures for both the simulator and the aircraft are carried out in terms of hours of operation rather than in numbers of maneuver repetitions, prior to integrating cost and training effectiveness, the training analyst should determine the average time required per maneuver in each training device. Then the appropriate transformations of axes of curves such as those in Figures 4 through 7 can be made such that the abscissae's unit of measure is units of simulator time and the ordinates' unit of measure is units of aircraft time.

Device operation costs. To determine economically optimal mixes of simulator and aircraft time, the training analyst must be provided the cost per unit of operating time for both devices. If this figure for the simulator is designated C_S, then the function describing the total cost of x units of simulator training time will be the product $C_S x$, as shown in Figure 8a. Likewise, if after x units of simulator training, y units of aircraft training are required, the total cost of this training will be the product $C_A y$, where C_A is the cost per unit of aircraft training time. Since it has been shown that the y units of required aircraft training time can be expressed as a function of x as $ae^{-bx} + c$, then the cost of required aircraft training can be more explicitly expressed as $C_A(ae^{-bx} + c)$ as in Figure 8b. Then, for any one maneuver, the total cost can be expressed as

$$C = C_S x + C_A(ae^{-bx} + c), \qquad (5)$$

which is illustrated graphically in Figure 8c.

Inspection of Figure 8c indicates it has a point at which total cost is minimized, and it can be shown mathematically** that equation 5 is at a minimum when

$$x = (\ln C_A + \ln a + \ln B - \ln C_S)\ (b^{-1}) \qquad (6)$$

If for any maneuver m this optimal value of x is denoted as $\acute{x}_m$, then total optimized training cost for all M maneuvers can be expressed as

$$C_{\acute{T}} = \sum_{m=1}^{M} \left[C_S \acute{x}_m + C_A\ (a_m e^{-b_m \acute{x}_m} + c_m) \right] \qquad (7)$$

* Note that for moderately large values of b, the value of ae^{-bx} very quickly approaches zero.

** $\frac{dC}{dx} = C_S - C_A abe^{-bx}$, which, when set at zero and solved for x, yields equation 6.

$\frac{d^2C}{dx^2} > 0$ (given a > 0 and b > 0) implies x in equation 6 represents a minimum.

and the raw savings realized will be, of course, the difference between $\underline{C}_T$ evaluated at $\underline{x} = 0$ and the $\underline{C}_T^*$ of equation 7.

Thus it can be seen that the model and methodology presented here are both viable and of great utility to the training analyst.

Further Considerations

Although the methodology presented here is fairly straightforward, there are some additional factors to be kept in mind in the details of applying its results in development of a simulator-based training system.

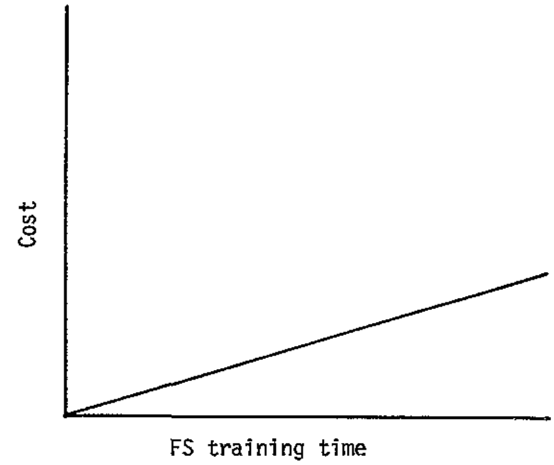
Effects of curriculum. It is an inescapable fact that, regardless of the level of technology and the sophistication of a simulator, its effectiveness is a function of how it is used, of how the trainer incorporates its features into a training program. The quantitative measures of effectiveness determined by this study are very much a function of how the IPs used the simulator as a training device. As the simulator instructional tactics are refined, the AH1FS's effectiveness should improve. Considered in this light, the trade-off curves determined by the study represent not the optimum effectiveness of the device, but the baseline effectiveness.

Restricted device availability. As mentioned in the introduction, most modern simulators are high cost assets and must be distributed over a large number of trainees. In all cases, the training analyst will have the device available for some finite period each day. In many cases the analyst is also faced with cycling through the curriculum a large number of students within a fixed number of training days. These restrictions determine the amount of simulator time that will be available to each student. Ideally, the amount of time allocable per student would be at least equal to the total optimal maneuver training times. In many instances, this is not the case and less than optimal training curricula must be set up according to some trade-off scheme.

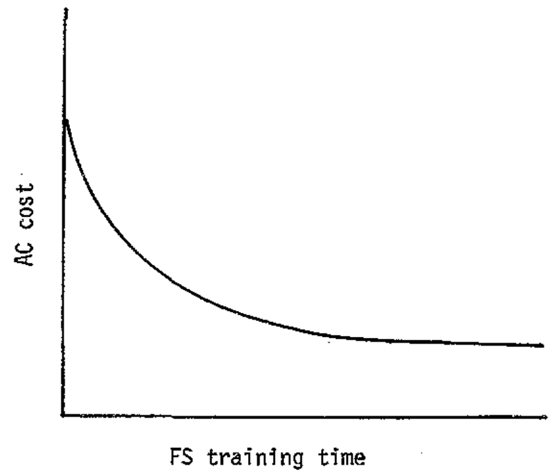
In his implementation of the integration procedures outlined here, Hopkins (7) ordered the simulator trainable maneuvers in terms of each maneuver's savings per hour of simulator operation. (In general, more savings per unit of simulator operating time accrue to those maneuvers for which the difference $\underline{a} - \underline{c}$ is great and the rate parameter $\underline{b}$ is large.) Choosing a hypothetical 3.5 hour availability per student, he simply cumulated the $\underline{x}^*$ values (in terms of time) down the rank-ordered list of maneuvers until they totalled 3.5 hours. Other trade-off schemes might alternatively involve such considerations as weighting each maneuver according to the danger associated with performing it in the aircraft.

Conclusions

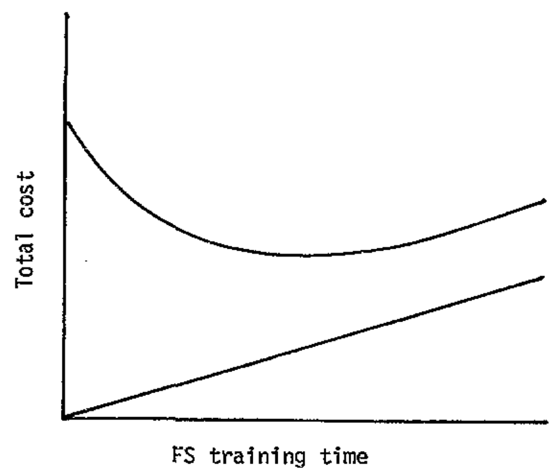
At the practical level, the model and methodology have been demonstrated as both viable and of utility. The model does not concern itself directly with such issues as fidelity and realism, but addresses directly the effectiveness of the simulator in decreasing required aircraft training time. Aircraft training time is expressed as a



a. Cumulative FS training cost as a function of FS training time.



b. Cumulative aircraft training cost as a function of FS training time.



c. Cumulative total cost as a function of FS training time.

Figure 8. Integration of simulator and aircraft training costs.

sum of two factors; the model can be easily expanded to include other factors such as student experience or aptitude or cumulative negative effects of simulator training. For mathematical rigor, the number of levels of the independent variable sampled should be at least one more than the number of free parameters estimated. With careful selection of levels of the independent variable, there is no requirement that some Ss be used for "control" data and receive no simulator training.

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