COST-EFFECTIVENESS OF FLIGHT SIMULATORS FOR MILITARY TRAINING

DR. JESSE ORLANSKY AND MR. JOSEPH STRING
Institute for Defense Analyses

INTRODUCTION

The purpose of this paper is to evaluate research and development on the cost and effectiveness of flight simulators used for training. The use of flight simulators for purposes other than training is not considered.*

The advantages of flight simulators for training purposes are well known. They permit close observation of pilot performance and immediate feedback which improves learning; they permit training pilots in many types of malfunctions not often encountered in flight; they are safe and permit training independent of weather, air traffic and the availability of aircraft; they save fuel, ammunition, targets, wear and tear on airplanes and, above all, the lives of pilots. But simulators also have some important disadvantages. Even the most advanced simulators have limited fidelity in external vision, platform motion and flight equations; they cannot provide the motivation and stress possible only in aircraft; and they are expensive to procure and to operate.

OPERATING COSTS OF FLIGHT SIMULATORS AND OF AIRCRAFT

The first question about the cost-effectiveness of flight simulators and aircraft concerns how much they cost to operate. For this purpose, we considered only "variable operating costs" which, by definition, include the costs of fuel, oil and lubrication, base maintenance materials, and that portion of depot maintenance which varies with flying hours and replenishment spares. Variable operating costs do not include the costs of crew and student salaries or for amortizing the purchase of simulators. We were able to find operating cost per hour data for 33 aircraft and simulators, shown in Figure 1. The data are based on actual utilization of aircraft and simulators for FY 1975 and FY 1976.

Most simulator/aircraft operating cost ratios vary from about 5 to 20 percent. The median value is about 12 percent. On the basis of operating costs alone, it is clear that it costs less to operate a flight simulator than the comparable aircraft.

The cost advantage of flight simulators says nothing about their effectiveness for training.

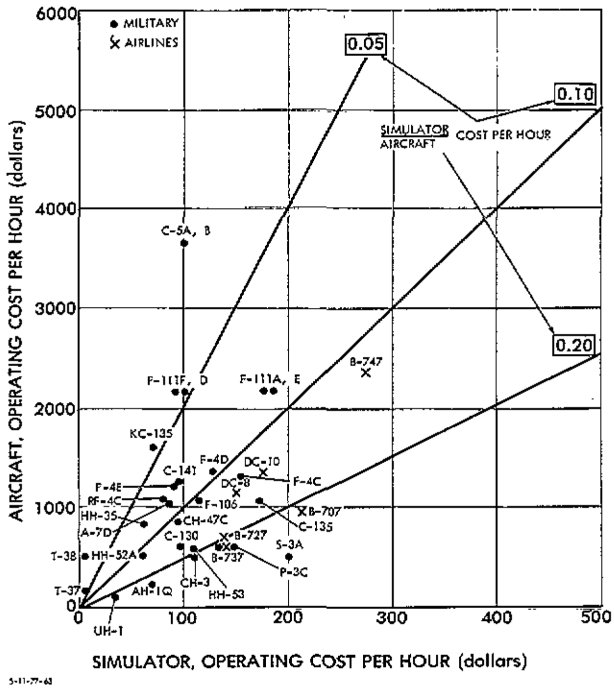


FIGURE 1. VARIABLE OPERATING COSTS PER HOUR FOR 33 SIMULATORS AND AIRCRAFT, FY 1975 AND FY 1976

THE EFFECTIVENESS OF FLIGHT SIMULATORS

There may be many ways to evaluate the effectiveness of flight simulators for use in military training. A favorite one is to have experienced pilots judge whether a simulator flies about the same way the comparable aircraft does. This is the test of "fidelity of simulation." Since we were concerned with the use of flight simulators for flight *training*, we were *particularly interested in* whether skills learned in a simulator carry over to an airplane. That is called "transfer of training," which we will define in a moment. Although simulators have been used for training almost since the airplane was invented (at least two flight simulators are known to have been available in 1910), many studies of training are concerned only with how well pilots perform in simulators. For our purposes, we wanted to know how well

*This study was performed for the Deputy Director of Defense Research and Engineering (Research and Advanced Technology). The report is listed in the References at the end of this paper.

pilots trained in simulators perform the same tasks in the air and whether training in simulators saves any flight time. There were 33 studies performed from 1939 to 1977 which provide this type of information.

These studies use simulators which vary widely with respect to types of aircraft, visual and motion systems; about half the studies were performed after 1970 when more modern simulators began to be available. The studies also vary with respect to level of pilot experience and the types of flying tasks that were examined. These studies show that pilots trained in simulators perform in aircraft as well as those trained only in aircraft, at least as measured by instructor pilot's ratings. This finding applies generally to such tasks as cockpit checkout and flight procedures, instrument flying, takeoff and landing; a few recent studies extend these findings to more acrobatic maneuvers and to air-to-ground gunnery. Simulator training also seems to save flight time.

However, the results of these studies are not reported in a common format which permit one to generalize on how much flight time can be saved by simulators. The Transfer Effectiveness Ratio (TER), as shown in Figure 2, can be used to show the amount of flight time saved as a function of the amount of time spent on training the same task in a simulator. Its use for such purposes was proposed by Stanley Roscoe (1971).

$$TER = \frac{Y_o - Y_x}{X}$$

Y_o = AIRCRAFT TIME, CONTROL

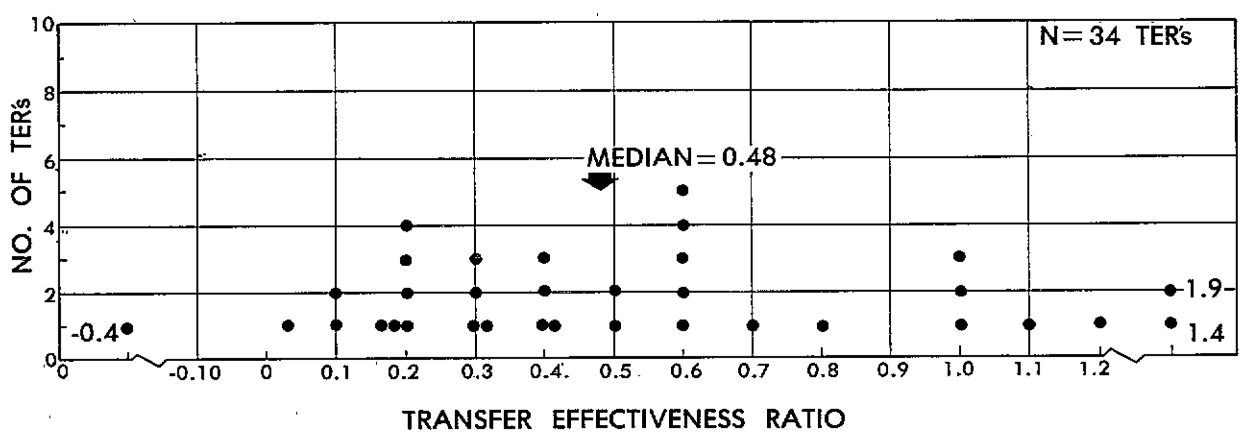
Y_x = AIRCRAFT TIME, EXPERIMENTAL

X = SIMULATOR TIME, EXPERIMENTAL

10-31-77-50

FIGURE 2. TRANSFER EFFECTIVENESS RATIO (TER)

Most studies of flight training in simulators, including the more recent ones, do not report Transfer Effectiveness Ratios. However, enough information was available in 22 studies from 1967 to 1977 to compute the 34 TERs shown in Figure 3. These TERs apply, variously, to instrument training, transition training, flight procedures, simulators with or without motion and so on. Overall, the TERs vary from -0.4 to 1.9, with a median value of 0.48. This may be interpreted as follows:



10-31-77-51

FIGURE 3. TRANSFER EFFECTIVENESS RATIOS
22 Studies (1967-1977)

Pilots trained in simulators use less flight time than those trained only in aircraft. The median amount of flight time saved is about half (0.48) of the time spent in the simulator. There is one negative value (-0.4) which, if true, means that pilots trained in a simulator in that study used more aircraft time than those not so trained. There is insufficient information on which to explain this case of "negative transfer." It is probably due to use of an inadequate simulator,but it is helpful to understand that not all uses of simulators necessarily save training time.

There are seven cases where the TER is one or more which means that more than one hour of flight time was saved for every hour spent in the simulator. This result should not be too surprising. It is possible to practice a task more often in an hour in a *simulator than in an aircraft*; e.g., one doesn't have to go around the traffic pattern to shoot a landing; one doesn't have to take time to set up a flight condition as in an airplane, because it can be set up instantly by the computer; one can get more feedback about performance in a simulator than in an airplane, and so on.

However, the highly positive TERS and the one negative TER are extreme values; the middle 50 percent of all values fall between 0.25 and 0.75; the median TER of the entire distribution is 0.48.

The TERs shown previously were divided into three groups based on the experience level of the pilots; i.e.,

highly experienced (i.e., airline pilots)

graduate (i.e., pilots who have already earned their wings), and

undergraduate pilots (i.e., student pilots who have not yet earned their wings).

The experience levels of these pilots, in effect, also describe the use of simulators for different types of training:

Level of Experience	Type of Training
highly experienced	transition flight procedures
graduate	transition instrument
undergraduate	familiarization instrument

The results are shown in Figure 4. Assuming that the TERs are reliable, the figure shows that undergraduate pilots save more aircraft time as a result of using simulators than do more advanced pilots. However, all groups of pilots who use simulators save some flight time. On the other hand, it costs more

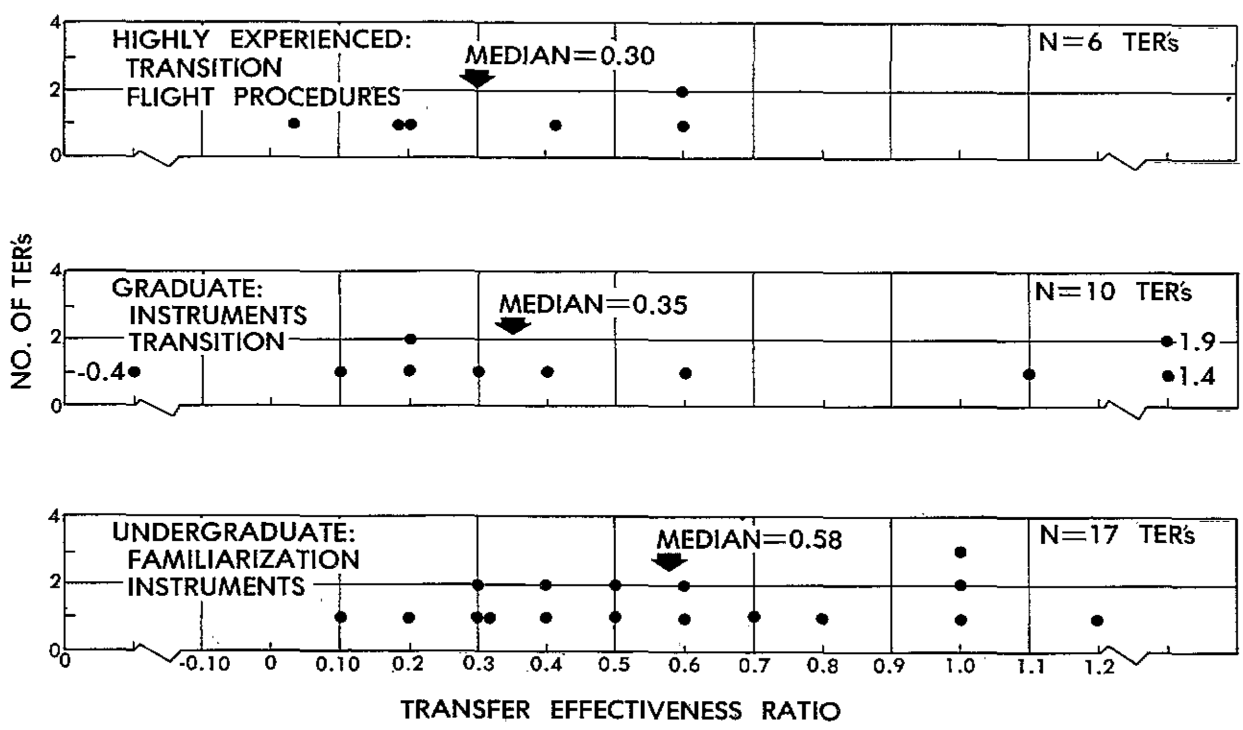


FIGURE 4. TRANSFER EFFECTIVENESS RATIOS AND PILOT EXPERIENCE

per hour to fly an advanced aircraft than one used by undergraduate pilots, but that is not considered here.

In a recent study, Transfer Effectiveness Ratios were determined for 24 different maneuvers when the CH-47 helicopter flight simulator was used for transition training (Holman, 1978). The findings (Figure 5) show that the effectiveness of this simulator varies widely according to the maneuvers on which it may be used for training. The TERs range from 0.0 to 2.8. Clearly, this simulator should not be used for training on some maneuvers. There is also a strong suggestion that this simulator has some limitations for training, probably on tasks that depend significantly on visual simulation.

MANEUVER	TER
Four wheel taxi	2.80
Cockpit run up	1.50
SAS off flight	1.33
Deceleration	1.25
Maximum take off	1.25
General air work	1.00
Steep approach	1.00
Two wheel taxi	1.00
Confined area recon	1.00
Hovering flight	.79
Normal take off	.75
Confined area approach	.75
Landing from hover	.69
External load briefing	.67
Take off to hover	.63
Traffic pattern	.61
Shallow approach	.58
Normal approach	.53
Confined area take off	.50
External load take off	.50
External load approach	.50
Pinnacle recon	.50
Pinnacle take off	.33
Pinnacle approach	.00

Source: Holman, G. L., "Suitability-for-training evaluation of the CH-47 flight simulator", ARI Ft. Rucker, 3 July 1978 (draft).

9-25-78-15

FIGURE 5. TRANSFER EFFECTIVENESS RATIOS FOR 24 MANEUVERS, CH-47 FLIGHT SIMLATOR (TRIALS TO CRITERION)

We believe that these studies warrant the following conclusions:

1. Flight simulators save aircraft time. Virtually all studies (21 out of 22) show that the use of flight simulators saves aircraft time. Pilots trained on specific skills in simulators need less time to perform these same skills in aircraft than do pilots trained on the same tasks only in aircraft.

2. Simulators are effective under many different conditions. Simulators have been shown to be effective for training undergraduate and graduate pilots, for training on many different types of aircraft, and for training on different types of tasks (e.g., landing, instrument flight, flight procedures, and flight familiarization). The finding also applies to the effectiveness of simulators with a variety of performance capabilities (e.g., with or without vision, with or without motion).

3. Effectiveness varies widely. There is a wide range in the degree of effectiveness reported with the use of flight simulators. Little systematic attention has been given to examining the factors that may influence the effectiveness of simulators. Since most studies do not use common measures, it is difficult to understand the reasons for the wide range in the effectiveness of different types of simulators or in their use for training on different tasks.

4. Effectiveness does not imply cost-effectiveness. The fact that flight simulators are effective for training does not necessarily imply that they are worth their cost.

We turn next to the question of the cost-effectiveness of flight simulators.

COST-EFFECTIVENESS OF FLIGHT SIMULATORS

In order to estimate the cost-effectiveness of flight simulators for training, we need data on the cost and the effectiveness of simulators and of aircraft for training pilots in particular maneuvers or tasks. There are only a few cases where such data have been collected.

A study by Povenmire and Roscoe (1973) shows exactly how a cost-effective analysis of training should be conducted. Student pilots were given either 0, 3, 7, or 11 hours of training on the Link GAT-1 simulator before being trained in an airplane. Figure 6 shows the number of hours needed by each group to pass the final flight check, and the number of aircraft hours saved by the simulator, compared to those trained only in the airplane. To the best of our knowledge, this is the only study performed so far in which the amount of time spent in a simulator was varied systematically; all other studies tend to use a fixed amount of simulator time.

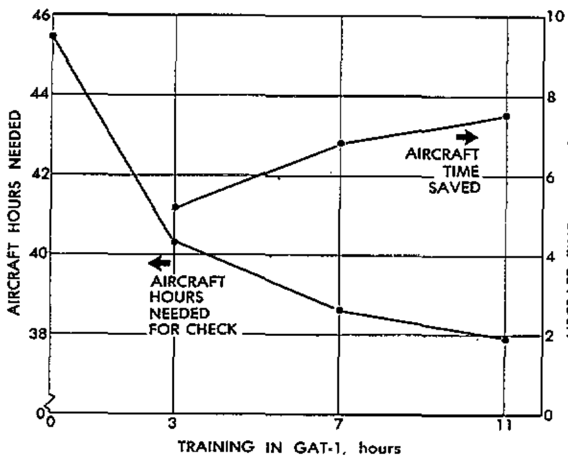


FIGURE 6. HOURS NEEDED FOR FINAL FLIGHT CHECK, PIPER CHEROKEE

Figure 7 shows the Cumulative Transfer Effectiveness Ratio (CTER) and the Incremental Transfer Effectiveness Ratio as functions of the amount of time spent in the simulator (CTER is the same as TER). Both ratios are reduced as the amount of time in the simulator *increases. This is an important finding be*cause it permits us to determine when the marginal utility of the simulator has been reached. A useful criterion is the tradeoff between the relative costs of operating a particular simulator and aircraft. In this *case, the simulator/aircraft operating cost* ratio is $\frac{\$16}{22}$ per hour or 0.73. Therefore, training in the simulator is cost-effective until the Incremental Transfer Effectiveness Ratio drops below the simulator/aircraft *operating cost ratio. This occurs at about 4* hours in the GAT-1 for training student pilots to pass the final flight check for a private pilot's license.

The Piper Cherokee is a simple airplane *and it is very inexpensive to operate;* i.e., $22 per hour. For most military aircraft the operating costs are between about $200 to $1400 per hour. As reported earlier, most simulator/aircraft operating cost ratios for military aircraft range between 0.05 and 0.20. *If those* ratios applied to the present data, it would have been economical to use the simulator for longer periods, perhaps as long as 10 to 20 hours.

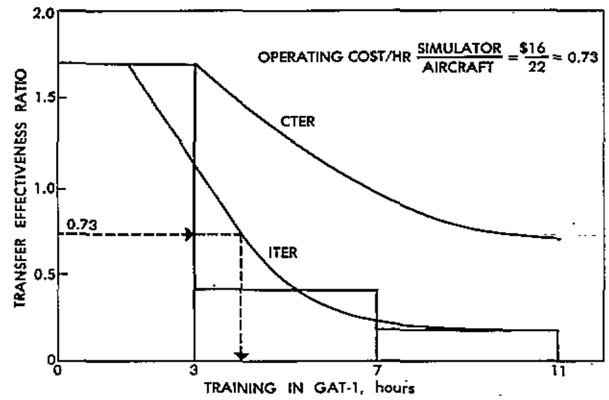


FIGURE 7. INCREMENTAL TRANSFER EFFECTIVENESS RATIO (ITER) AND OPERATING COST RATIO

The Coast Guard operates two helicopters, the HH-52A and the HH-3F (Isley, Corley and Caro, 1974). In 1974, it introduced the Variable Cockpit Training System (VCTS). This simulator has two cockpits and can simulate either or both helicopters; each has a motion base with six degrees of freedom but no visual system. The procurement cost was $3.1M (Figure 8); operating costs of the simulator are very much less than for the helicopters.

PROCUREMENT COST, VARIABLE COCKPIT TRAINING SYSTEM (VCTS)	$3.1M
OPERATING COST PER HOUR (1974 DOLLARS)	
HH-52A	$504
HH-3F	815
VCTS	59

FIGURE 8. HELICOPTER TRAINING, U.S. COAST GUARD

The Coast Guard also introduced a new training syllabus for its new simulator. Figure 9 shows the number of aircraft and simulator hours per pilot required to complete various types of training before and after introduction of the simulator. Aircraft hours required per pilot were reduced in all cases. The total cost of flight training used to be $3 million per year; now the total cost of flight time and simulator time is $1.6 million per year, a realized benefit of almost $1.5 million.

There is also an additional estimated benefit because the simulator is now used instead of the helicopter in preparation for the check ride and emergency procedures test in proficiency training. This is estimated to cost $106K,but it avoids costs of about $1.1 million per year.

Thus, the procurement cost of the VCTS can be amortized in either 2.1 years (Figure 10) or in 1.2 years, depending on which benefits are used to make this assessment.

PROCUREMENT COST OF VCTS	$3.1M
REALIZED BENEFIT PER YEAR	$1.5M
ESTIMATED BENEFIT PER YEAR	1.1
TOTAL	$2.6M

$$\frac{\text{PROCUREMENT COST}}{\text{REALIZED BENEFIT}} = \frac{\$3.1\text{M}}{1.5 \text{ PER YEAR}} = 2.1 \text{ YEARS}$$

$$\frac{\text{PROCUREMENT COST}}{\text{TOTAL BENEFIT}} = \frac{\$3.1\text{M}}{2.6 \text{ PER YEAR}} = 1.2 \text{ YEARS}$$

FIGURE 10. AMORTIZATION, U.S. COAST GUARD

TYPE OF TRAINING	PILOTS/YR	BEFORE		AFTER			BENEFITS (000)
		FLIGHT HRS	COSTS (000)	FLIGHT HRS	SIMULATOR HRS	COSTS (000)	
REALIZED BENEFITS							
HH-52A TRANSITION	30	31	$ 469	28	9	$ 439	$ 30
QUALIFICATION	18	78	708	36	11	338	370
PROFICIENCY	300	3	454	0	6	106	348
HH-3F TRANSITION	32	36	939	23	15	628	311
PROFICIENCY	200	3	489	0	8	94	395
TOTALS	580		$3059			$1605	$1454
ESTIMATED BENEFITS							
HH-52A PROFICIENCY	300	3		0	3	53	401
HH-3F PROFICIENCY	200	4.5	734	0	4.5	53	681
TOTALS	500		$1188			$ 106	$1082

10-31-77-58

FIGURE 9. ESTIMATED TRAINING COSTS IN THE COAST GUARD BEFORE AND AFTER INTRODUCTION OF THE VCTS SIMULATOR

(1974 Dollars)

In 1977, Browning, Ryan, Scott and Smode (1977) compared the cost and effectiveness of two programs for transition training of naval pilots to fly the P-3C, a four-engine turboprop aircraft used in anti-submarine warfare. The two programs involve the use either of an old simulator (2F69D) or a new one (2F87F); both simulators provide individual and crew training for the pilot, co-pilot and flight engineer.

The following devices were used in the study:

- Cockpit Procedures Trainer (CPT) Device 2C45. Provides training in power plant management and systems procedures for normal and emergency operations. This device is actually an obsolete P-3 operational flight trainer from which flight dynamics, motion, and unneeded systems have been removed.

- Operational Flight Trainer (OFT) Device 2F69D. This OFT is a solid state analog device (1966 era) which simulates flight dynamics, systems, navigation, and communications for P-3A/B aircraft. It provides motion with 3 degrees of freedom, but no visual simulation.

- Operational Flight Trainer (OFT) Device 2F87F. This is a digital device which simulates the P-3C Orion aircraft. It provides motion with 6 degrees of freedom and vision (50° wide x 38° high) by means of a TV model board system (15 nmi x 5 nmi) for low-altitude maneuvers such as takeoff, landing, and instrument approaches. It replaces the 2F69D.

All pilots were newly designated first-tour naval aviators who possessed Standard Instrument Cards. All had completed undergraduate multi-engine training on the S-2, a small two-engine propeller-driven aircraft. Hours given to training in simulators prior to flight are shown in Figure 11: 22 hours in the old program, 40 in the new one. After training in the simulator, performance was measured in the aircraft on 20 of the 45 tasks specified in the Familiarization and Instrument phase of transition training (e.g., engine start, brake fire, abort takeoff, approach, three engine landing). The critical data were the hours required by each group to perform these tasks proficiently in the aircraft; i.e., as judged acceptable by the instructor pilot. The control group required 15 hours in the aircraft per pilot, the experimental group required 9. There was no difference between the groups in flight proficiency in the air. These findings are supported by more recent work at VP-30, (Browning, Ryan and Scott, 1978).

DEVICE	HOURS REQUIRED PER STUDENT: CONTROL N=16	HOURS REQUIRED PER STUDENT: EXPERIMENTAL N=27	OPERATING COST PER HOUR
COCKPIT PROCEDURES TRAINER (2C45)	13	16	$104
OPERATIONAL FLIGHT TRAINER (2F69D)	9	--	134
OPERATIONAL FLIGHT TRAINER (2F87F)	–	24	144
AIRCRAFT P-3C	15	9	2284
TOTAL HRS	37	49	
TOTAL COST PER YEAR (200 PILOTS)	$7.1M	$4.6M	

FIGURE 11. ANTI-SUBMARINE WARFARE, P-3C

The new P-3C simulator costs $4.2M (Figure 12). Compared to the control program, the experimental program is estimated to save $2.5M per year (assuming a projected load of 200 pilots per year). On this basis, the procurement cost of the new simulator would be amortized within two years.

PROCUREMENT COST DEVICE 2F87F		$4.2M
OPERATING COSTS PER YEAR (200 PILOTS)		
CONTROL		$7.1M
EXPERIMENTAL		4.6
	SAVINGS	$2.5M PER YEAR

$$\frac{\text{PROCUREMENT COST}}{\text{SAVINGS PER YEAR}} = \frac{\$4.2M}{2.5M/YR} = 1.7 \text{ YEAR}$$

FIGURE 12. P-3C SIMULATOR AMORTIZATION

An analysis of investment costs also favors the new program (Figure 13). Based on

DEVICE	PRESENT VALUE	CONTROL N	CONTROL COST	EXPERIMENTAL N	EXPERIMENTAL COST
CPT (2C45)	$1390K	1	$1390K	1	$1390K
OFT (2F69D)	1396	1	1396		
OFT (2F87F)	4225			1	4225
AIRCRAFT P-3C	13.7M	7	95,900	4.2	57,540
TOTAL			$ 98.7M		$ 63.2M
10-YEAR LIFE CYCLE COST (DoDI 7041.3)			$125M		$ 81M

FIGURE 13. P-3C INVESTMENT COSTS

required flight hours, the control program would require 7 aircraft, the new one 4.2 aircraft. The investment cost of the new program is $63.2 million compared to $98.7 million for the old one. The 10-year life cycle cost of the new program is $81 million compared to $125 million for the old one.

One airline provided an analysis of its current training costs for 1976 for the use of simulators and aircraft (Figure 14). It uses its simulators for training purposes for 26,000 hours each year and, in addition, its aircraft for over 1,100 hours. The cost of these training hours was $6.8 million in 1976. This airline estimated what it would cost if all these training hours had to be performed only in aircraft. That total would be about $32.1 million a year. By the use of simulators, this airline estimates that its annual training costs are about 21 percent of what they would be if they had to depend only on aircraft.

AIRCRAFT	TOTAL TRAINING HOURS		COSTS		SIMULATOR & AIRCRAFT AS PERCENTAGE OF AIRCRAFT-ONLY COSTS
	SIMULATOR	AIRCRAFT	SIMULATOR & AIRCRAFT (ACTUAL)	AIRCRAFT ONLY (ESTIMATE)	
A	3,511	186	$1.2M	$ 6.0M	19%
B	8,997	272	2.1	10.6	20
C	12,277	547	2.9	11.8	25
D	1,262	118	0.6	3.7	17
TOTAL	26,047	1,123	$6.8M	$32.1M	21%

FIGURE 14. ANALYSIS OF TRAINING COSTS BY ONE AIRLINE, 1976

The flight simulators used by this airline cost $17.5 million (Figure 15). The airline estimates that it saves $25 million per year by the use of these simulators compared to what it would cost if it had to use only aircraft for training. This airline estimates that the savings it realizes by the use of simulators would permit it to amortize their procurement cost in less than 9 months.

These studies are summarized in Figure 16. Only a few reports have examined the cost-effectiveness of flight simulators in actual practice. The findings support the use of simulators. Use of the Navy P-3C simulator and the Coast Guard VCTS simulator saved sufficient flight time to amortize procurement costs within two years. An analysis provided by an airline suggests an even shorter amortization period.

PROCUREMENT COST	
SIMULATORS	$17.5M
COST OF TRAINING	
AIRCRAFT ONLY	$32.1M PER YEAR (ESTIMATE)
SIMULATORS AND AIRCRAFT	6.8 PER YEAR (ACTUAL)
SAVINGS	$25.3M PER YEAR (ESTIMATE)
PROCUREMENT COST / SAVINGS PER YEAR	= $17.5M / $25.3M PER YEAR = 8.3 MONTHS

FIGURE 15. ESTIMATES OF AMORTIZATION (AIRLINE)

	APPLICATION	PILOT LOAD	ESTIMATED AMORTIZATION OF SIMULATOR
PRIVATE PIPER CHEROKEE GAT-1	FINAL FLIGHT CHECK	—	ESTABLISHES OPTIMUM USE OF SIMULATOR
NAVY P-3C 2F87F	TRANSITION TRAINING	200	2 YEARS
COAST GUARD HH-52A HH-3F VCTS	TRANSITION, PROFICIENCY TRAINING	500	2 YEARS
AIRLINE	TRANSITION, RECURRENT TRAINING	—	9 MONTHS

FIGURE 16. SUMMARY OF COST-EFFECTIVENESS STUDIES

DISCUSSION

It is no surprise to find that flight simulators cost less to operate than do aircraft. Most simulator/aircraft operating cost ratios fall in the range of 0.05 to 0.20. The use of flight simulators appears to save flight time in aircraft. The range of these values, expressed as Transfer Effectiveness Ratios, varies from close to zero to well over one, with a median at about 0.50. Thus, there is a clear implication that flight simulators can be cost-effective for training providing careful attention is given to the tasks and maneuvers for which they are used and that flight simulators are not used beyond the point of marginal utility for these maneuvers. Only a few studies of cost-effectiveness have actually been conducted. Here, it appears that the cost of procuring flight simulators can be amortized within about two years.

A few words should be said about some recent developments that can significantly affect the cost-effectiveness of flight simulators. The first concerns the need for platform motion in flight simulators. A six degree of freedom synergistic motion platform can cost up to $0.6 million. A series of studies since 1974 have shown that there is no difference in performance in aircraft between pilots trained in simulators with motion and pilots trained without motion (Koonce, 1974; Jacobs and Roscoe, 1975; Woodruff and Smith, 1974; Gray and Fuller, 1977; Woodruff, Smith et al., 1976; Martin and Waag, 1978). Although more work remains to be done, it appears that modern flight simulators for center thrust aircraft, with good visual systems, do not need platform motion. Recent procurements of F-16 and A-10 simulators by the Air Force do not include platform motion. It is still an open question whether platform motion is needed in simulators for wide-bodied aircraft.

Incidentally, a concern with improving the fidelity of flight simulators led to the improvement of platform motion over the past 15 years. It is, of course, true that pilots perform better in simulators with motion than in simulators without motion. Until Koonce's study in 1974, no one had thought to ask whether platform motion in simulators contributes anything to performance in aircraft. The answer so far seems to be "not much." It also suggests that, except possibly to improve pilot acceptance, the test of fidelity may not always give us a good answer.

Visual systems for flight simulators are very impressive devices. So is their cost, which is now in the range of $6 to $8 million per copy. New computer-generated visual systems can provide types of training in simulators that have not been possible up to now. They can present scenes needed, for example, for training in aerial refuelling, air-to-air combat, and nap-of-the-earth flying. The real question concerns the degree of realism required to make visual displays useful for such types of training. Very little data are now available to help us specify the visual requirements for the most expensive component in a modern flight simulator. There is one study in which Air Force pilots were trained to land a B-707 using one of three different visual simulation systems and then measured for their ability to land a KC-135 aircraft, the tanker version of the B-707 (Thorpe, Varney et al., 1978). The visual scenes were produced by a day computer-generated imagery (CGI) system, a day TV model board system and a night-only computer-generated imagery system. Pilot performance on landing the aircraft was superior for those trained on the CGIs to those trained on the TV model board; there was no difference between the two CGI systems as far as landing performance is concerned. If we accept the results of this one study, the less expensive, night-only CGI is all we need for training pilots how to land. In all fairness, further studies on other maneuvers and other types of simulators are needed before we can specify what type of visual imagery is good enough for various types of training. Here again, the image with the greatest fidelity and cost may not be all that necessary.

One final point. It is quite likely that flight simulators will be found to be cost-effective and as a result, there may be more pressure to reduce flying hours. Flight simulators, however useful, are not a substitute for training in aircraft. Military training must proceed from simulators to aircraft and there is some minimum amount of flight time required below which one cannot go. This is necessary to maintain combat skills and to exercise support systems, such as maintenance and command and control, on which military readiness depends. More attention must clearly be given to establish what these minimum flying hours should be.

CONCLUSIONS

1. Flight simulators cost less to operate than do aircraft; most simulator/aircraft operating cost ratios fall within the range of 0.05 to 0.20.

2. Flight simulators save flight time. Transfer Effectiveness Ratios vary widely, with a median value of about 0.50. This means that about half the time spent in simulators shows up as savings in flight time, with variations probably due to type of simulator and type of maneuvers for which the simulator is used.

3. The cost of procuring flight simulators can be amortized in about two years.

4. Research and development is needed to improve our knowledge about the optimum use of simulators for various types of flying tasks. There is also a need to examine the need for platform motion in simulators for wide-bodied aircraft and for the degree of realism needed in new visual displays.

5. There is a need to establish the marginal utility of flight simulators when used for various types of training.

6. There is a need to establish the

minimum amounts of flying hours needed to maintain military readiness in various types of aircraft.

REFERENCES

Browning, R.F., L.E. Ryan, P.G. Scott, "Utilization of Device 2F87F OFT to Achieve Flight Hour Reductions in P-3 Fleet Replacement Training," TAEG Report No. 54, Training Analysis and Evaluation Group, Orlando, Fla., April 1978.

Browning, R.F., L.E. Ryan, P.G. Scott and A.F. Smode, "Training Effectiveness Evaluation of Device 2F87F, P-3C Operational Flight Trainer," TAEG Report No. 42, Training Analysis and Evaluation Group, Orlando, Fla., January 1977.

Gray, T.H., and R.R. Fuller, "Effects of Simulator Training and Platform Motion on Air-to-Surface Weapons Delivery Training," AFHRL-TR-77-29, Williams Air Force Base,Ariz. Flying Training Division, Air Force Human Resources Laboratory, July 1977.

Holman, G.L., "Suitability-for-Training Evaluation of the CH-47 Flight Simulator," Army Research Institute, Fort Rucker, Ala., 3 July 1978 (draft).

Isley, R.N., W.E. Corley and P.W. Caro, "The Development of U.S. Coast Guard Aviation Synthetic Equipment and Training Programs," FR-D6-74-4, Human Resources Research Organization, Fort Rucker, Ala., October 1974.

Jacobs, R.S. and S.N. Roscoe, "Simulator Cockpit Motion and the Transfer of Initial Flight Training" in New Concepts for Training Systems, 8th NTEC/Industry Conference Proceedings, Naval Training Equipment Center, Orlando, Fla., p. 113-122, 18-20 November 1975.

Koonce, Jefferson M., "Predictive Validity of Flight Simulators as a Function of Simulator Motion," Human Factors, 21, 215-223, 1979.

Martin, E.L. and Waag, W.L., "Contributions of Platform Motion to Simulator Training Effectiveness: Study I--Basic Contact," AFHRL-TR-78-15, June 1978, Study II Aerobatics, AFHRL-TR-78-52, September 1978, Williams Air Force Base, Ariz.: Flying Training Division, Air Force Human Resources Laboratory.

Orlansky, Jesse and Joseph String, "Cost-Effectiveness of Flight Simulators for Military Training," IDA Paper P-1275, Institute for Defense Analyses, Arlington, VA, August 1977, (3 volumes) DDC No's. AD A052,801, AD A049-979, AD C013-000.

Povenmire, H.K., and S.N. Roscoe, "Incremental Transfer Effectiveness of a Ground-Based Aviation Trainer," Human Factors, 15, 534-542, 1973.

Roscoe, S.N., "Incremental Transfer Effectiveness," Human Factors, 14, 363-364, 1971.

Thorpe, J.A., N.E. Varney, R.W. McFadden, W.D. LeMaster and L.H. Short, "Training Effectiveness of Three Types of Visual Systems for KC-135 Flight Simulators," AFHRL-TR-78-16, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, June 1978.

Woodruff, R.R. and J.F. Smith, "T-4G Simulator and T-4 Ground Training Device in USAF Undergraduate Pilot Training," AFHRL-TR-74-78, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, November 1974.

Woodruff, R.R., J.F. Smith, J.R. Fuller and D.C. Weyer, "Full Mission Simulation in Undergraduate Pilot Training: An Exploratory Study," AFHRL-TR-76-84, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, December 1976.

ABOUT THE AUTHORS

DR. JESSE ORLANSKY is a member of the research staff of the Institute for Defense Analyses, Arlington. He has been studying the cost-effectiveness of various types of military training for the Office of the Under Secretary of Defense for Research and Engineering. He received a B.S.S. from City College of New York and a Ph.D. from Columbia University.

MR. JOSEPH STRING is a member of the research staff of the Institute for Defense Analyses, Arlington, where he has been responsible for many systems and cost analyses of military programs. His experience includes economic and systems analyses at the Rand Corporation, Research Analysis Corporation, and the Program and Policy Office of the California Department of Finance. He holds a Master's Degree and is a candidate for the Ph.D. in economics at the University of California, Los Angeles.