Transfer and Cost Effectiveness as Guides to Simulator/Flight Training Device Use

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ABSTRACT

As fuel prices climb and aircraft operating expenses follow suit, the training costs incurred by aviation students continue to rise. Responsible aviation programs must seek ways to provide safe and effective training while minimizing their students' training costs. To accomplish this, many aviation programs utilize flight simulation of some form as a complement to training in the aircraft. Simulation can be offered at greatly reduced per hour costs when compared to the aircraft, and as studies have shown, provides positive transfer of training from the simulated environment to the aircraft. Positive transfer of training implies that students will benefit from training in the simulated environment. This is only the case when the transfer effectiveness ratio (TER) is above a given value. It is the purpose of this paper to demonstrate a method of evaluating the cost effectiveness of a training device by using the TER and the cost effectiveness ratio (CER.) By using these tools, the use of simulation will be of maximum benefit, i.e. reduced training costs, to aviation programs and their students.

INTRODUCTION

Training is "the act, process, or method of one that trains" (Merriam-Webster's Collegiate Dictionary, 2005, p. 1326). In aviation, as in all other endeavors, training ideally should take place in the same conditions and environment as the circumstances for which one is being trained. This translates into conducting pilot training in an actual aircraft while in flight. While this form of training may be ideal, it is also very expensive. With the current Federal Aviation Administration's (FAA) mandated 40 flight hours necessary to apply for the private pilot certificate under Part 61 (Code of Federal Regulations [CFR], 2007, Part 61), a small aircraft renting for $100 per hour (including averaged instructor's fee) will cost the student $4000 to receive the required time/training. This is the minimum number of hours necessary; however, the FAA indicates that the average number of hours actually received by applicants for the private pilot certificate extends upwards to 75 hours (Federal Aviation Administration [FAA], 2006), thereby increasing the hypothetical cost to $7500. Rising fuel and aircraft acquisition costs will also affect the cost of training by rapidly inflating the per hour cost of operating the aircraft.

For the student of a collegiate aviation training program requiring students to complete at least the commercial pilot's certificate, these costs are substantial given the 190 hour FAA minimum flight hours necessary to apply for the commercial pilot certificate under Part 141 (CFR, 2007, Part 141) and the added expense of tuition and fees for their college education. In light of this, ground-based trainers provide a training environment similar to the actual aircraft while at a reduced per hour cost.

TRANSFER EFFECTIVENESS RATIO

The transfer effectiveness ratio (TER) (Roscoe & Williges, 1980) is a means by which the benefit of training in a simulated environment can be measured by recognizing the positive effects seen when transitioning to the actual environment. The method by which the TER is calculated is as follows:

$$TER = \frac{Y_O - Y_X}{X}$$

Where:

- Y_O = iterations for a control group to meet a standard in the aircraft
- Y_X = iterations for an experimental group to meet a standard in the aircraft after having received prior training in a simulated environment
- X = iterations for an experimental group to meet a standard in a simulated environment prior to training in the aircraft

The numerator in the TER represents the relative benefit or detriment of prior training in a simulated environment. Positive numerators indicate less airplane iterations were required of a student who had prior training in a simulated environment than were required by a student who only trained in the actual environment, i.e. the simulated experience positively transferred to the actual environment. On the other hand, negative numerators indicate more iterations were required of a student who had prior simulated experience, i.e. bad habits gained in the simulated environment required extra iterations in the actual environment to overcome their negative effect, so a negative transfer. Numerators equal to zero represent a situation where prior simulated experience neither adds to nor takes away from a student's experience, or no transfer. Obviously the only acceptable option is that of positive transfer if simulation is to be used; however, the amount of time spent in simulation to achieve positive transfer is critical. For example, if simulator training reduced the iterations to reach proficiency in a given task by five iterations, the transfer would be positive.

$$Y_O - Y_X = 5$$

If five simulator iterations were required to do so, the TER would equal one.

$$TER = \frac{Y_O - Y_X}{X} = \frac{5}{5} = 1$$

If twenty simulator iterations were required, the TER would still be positive, but the transfer effectiveness would be much lower.

$$TER = \frac{Y_O - Y_X}{X} = \frac{5}{20} = 0.25$$

SIMULATION IN AVIATION

In aviation, the actual environment refers to an aircraft in flight. The simulated environment consists of any ground-based system which seeks to represent in some way an aircraft in flight. The personal computer-based aviation training device (PCATD) is a relatively inexpensive (several thousand dollars) system driven by a laptop or desktop computer running a flight simulation program (FAA, 1997). An onscreen representation of a cockpit with instrumentation is interfaced by means of flight, avionics, and other cockpit controls connected to the computer. A more accurate representation of an aircraft's cockpit, whether of a general or specific aircraft, is achieved by using a flight training device (FTD) or a flight simulator. FTDs and flight simulators represent full sized cockpit environments and typically have visual systems (CFR, 2007, Part 61). Flight simulators have the added benefit of force cueing, to further envelope the student in a more realistic training environment by giving the sensation of motion. FTDs are many times more expensive than PCATDs, hundreds of thousands of dollars, while full motion flight simulators reach into the millions of dollars.

No matter which level of these devices is used, the owner of the device must charge a per hour fee in order to offset the cost of the device, the cost of maintaining the device, and any other costs associated with the device's operation. This fee may be minimal for a PCATD, but can be substantial for the FTD or flight simulator. This fee must be considered, in conjunction with the transfer effectiveness of the simulation device, when incorporating simulation into a training program.

COST EFFECTIVENESS RATIO

TERs have been calculated and reported in many studies, the majority of which show positive transfer (Orlansky & String, 1977; Rantanen & Talleur, 2005; Taylor et al., 1999). Although positive TERs are a necessary consideration when evaluating the benefits of a particular simulation device and training methodology, positive *TER* values don't necessarily mean that the simulation device should be used. When considering the most directed and beneficial use of simulation devices, the TER is only the beginning. Another way of looking at the TER is as follows:

$$TER = \frac{\begin{matrix} aircraft\ \ iterations\ \ saved \\ by\ \ prior\ \ simulation \end{matrix}}{\begin{matrix} simlation\ \ iterations\ \ used \\ prior\ \ to\ \ aircraft\ \ iterations \end{matrix}}$$

In other words, this is a ratio of aircraft iterations to simulation iterations. This ratio can be transformed from a ratio of iterations to a ratio of time as follows:

$$TER \cdot \theta = \frac{\begin{matrix} aircraft \ \ time \ \ saved \ \ by \\ prior \ \ simulation \end{matrix}}{\begin{matrix} simlation \ \ time \ \ used \\ prior \ \ to \ \ time \ \ in \ \ aircraft \end{matrix}}$$

Where:

$$\theta = \frac{t_O}{t_X}$$

t_O = average time per iteration to perform a particular task in the aircraft

t_X = average time per iteration to perform a particular task in the simulation device

With the ratio now consisting of times, the per hour fees associated with the aircraft and simulation device can be applied as follows:

$$TER \cdot \theta \cdot \phi = \frac{\begin{matrix} aircraft \ \ fees \ \ saved \ \ by \\ prior \ \ simulation \end{matrix}}{\begin{matrix} simlation \ \ fees \ \ spent \\ prior \ \ to \ \ aircraft \ \ iterations \end{matrix}}$$

Where:

$$\phi = \frac{f_O}{f_X}$$

f_O = Per hour operating fee for the aircraft

f_X = Per hour operating fee for the simulation device

This new ratio of money saved in the aircraft to money spent in the simulation device provides a very useful metric for evaluating when simulation is or is not cost effective in a training program. This becomes the cost effectiveness ratio (CER) and is represented by the following equation.

$$CER = TER \cdot \theta \cdot \phi$$

The CER, unlike the TER, cannot simply be a positive number for favorable simulation cost effectiveness to occur. Since the numerator indicates the amount of money saved in the aircraft, and the denominator indicates the money spent in simulation, CER values greater than one represent more aircraft fees saved than simulation dollars spent. This represents a net savings to the student. For CER values less than one but greater than zero, money was saved in the aircraft; however, the money spent in simulation outweighed the money saved, thereby imparting more cost to the student than if the student had trained in the aircraft alone. CER values equal to one represent equal amounts of aircraft fees saved and simulation fees spent. In this situation, no difference as far as cost is concerned is apparent between aircraft only training and aircraft/simulation combined training. Therefore, only CER values greater than one represent positive cost effectiveness.

To further develop the usefulness of cost effectiveness, the components which compose the CER must be examined. As stated previously, the CER is the product of the TER, the time ratio, and fee ratio, and must be greater than one for positive cost effectiveness. This is shown in the following equation.

$$CER = TER \cdot \theta \cdot \phi > 1$$

Solving the inequality on the right for the *TER* yields:

$$TER > \frac{1}{\theta \cdot \phi}$$

This inequality reveals a minimum value of the TER necessary to provide a positive CER. As seen above, this TER value must be greater than the reciprocal of the product of the time and fee ratios. At this point a simplifying assumption will be introduced. For FTDs and flight simulators with realistic cockpits and controls, it will be assumed that the average time per iteration in the FTD/flight simulator will be the same as the average time per iteration in the aircraft. With this assumption, $\theta = 1$, the minimum TER necessary for positive cost effectiveness is found as follows:

$$TER > \frac{1}{\phi}$$

The TER for any particular task need only be greater than the reciprocal of the fee ratio, ϕ, in order for FTD/flight simulator use to be cost effective.

DISCUSSION

The value of ϕ is readily available for an aviation program with a set fee schedule. For example, if a program charges $100 per hour (including instructor's fee) for an aircraft and $50 per hour (also including instructor's fee) for an FTD, $\phi = 2$, and the corresponding TER for each task trained in the FTD must be greater than 0.5 in order to maximize the cost savings to a student. At this point an aviation program would need to know the TER for each task to be trained in order to make this evaluation. Studies such as that by Macchiarella, Arban, and Doherty (2006) have evaluated the transfer effectiveness from an FTD to an airplane for a given set of standard required pilot tasks (FAA, 2002.) While the overwhelming majority of the TERs in this study were positive, over half were less than 0.5. If the hypothetical value of $\phi = 2$ were to be used for this case, the aviation program could remove all non-cost effective tasks from FTD lessons thereby reducing the training costs to students.

It is apparent that the larger the value of ϕ, the lower the TER may be and still deliver positive cost effectiveness. Large ϕ values will arise when the difference in cost of the airplane versus the simulation device are large. This large difference will be realized for relatively expensive aircraft and/or inexpensive simulation devices. Accordingly, the use of simulation devices will most certainly be cost effective when training pilots to operate large, costly turbine-powered aircraft. For operators of such aircraft, even full-motion flight simulators may be many times less expensive to operate than the aircraft. For operators of small, reciprocating-engine aircraft, PCATDs will most likely provide positive cost effectiveness due to their very low operating costs. It is for the operators of small, reciprocating-engine aircraft using FTDs or flight simulators that the determination must be made as to the cost effectiveness of the device.

CONCLUSION AND RECOMENDATIONS

Positive TERs are necessary to justify the use of any simulation device. Taken one step further, the TERs must also be greater than the reciprocal of the fee ratio, ϕ, to provide positive cost effectiveness as given by the CER. It is the recommendation of the author that aviation programs should seek to determine the TERs for tasks to be trained in their FTDs/flight simulators, and only those tasks which provide positive cost effectiveness should be trained in a simulation device. In this way, aviation programs can provide more cost effective training for their students.

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