# A Study on Transfer Effectiveness and Appropriate Training Hours in Airplane Simulators

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**Abstract**

This study is to answer questions regarding appropriate training hours, transfer effectiveness, cost reduction effects, and quantity of airplane simulators, which are typical concerns of simulator customers and operators. Technical papers and reports on simulator training effectiveness are reviewed and analyzed as well as relevant regulations of FAA (Federal Avaiation Administration). The papers and reports show similar trends with different figures, which is inherent nature of experimental studies. The primary contribution of this study is to formulate rules to determine appropriate simulator training hours and cost reduction ratios based on the previous works on TER (Transfer Effective Ratio). Cases studies show reasonable results compared with present practices in civil and military training schools.

## 1 Introduction

This study is to answer questions regarding appropriate training hours, transfer effectiveness, cost reduction effects, and quantity of airplane simulators, which are typical concerns of simulator customers and operators. Technical papers and reports on simulator training effectiveness are reviewed and analyzed as well as relevant regulations of FAA (Federal Avaiation Administration) such as Part 61 and 141. The papers and reports show similar trends with different figures, which is inherent nature of experimental studies.

According the studies of Orlansky et al (Jessi O. and Joseph S., 1983,1984) in early 1980's, operating costs of flight training simulators are between 5% and 20% of those of actual airplanes, while the average is about 8%. Recent study shows higher TER (Transfer Effective Ratio). More information about TER can be found at http://www.trainingsystems.org/ publications/simulation/roi_effici.cfm. TER proposed by Roscoe (1971) is a standard tool to be used in this paper. Reviews of technical papers and reports on training effectiveness are summarized as follows:

- Typical TER is over 0.33.
- Motion platforms contribute to transfer of training for unintended maneuvers due to turbulences and engine outs.
- Most training centers and schools, either military or civil, allocate 30%~50% training hours in simulators, which agrees to FAR policies in Part 61 and 141.
- Most civil transport airlines operate FSTD (Flight Simulation Training Devices) with ratios between 1:10 and 1:20 (FSTD : Airplanes).

The primary contribution of this study is to formulate rules to determine appropriate simulator training hours and cost reduction ratios based on the previous works on TER reviewed in this paper. Cases studies show reasonable results compared with present practices in civil and military training schools.

## 2 Analyses of Training Effectiveness Studies

### 2.1 Operating Costs of Flight Training Simulators

US Army estimated $68M of flight training expenses were saved in FY 1994, and US Reserves reduced the training cost of $55M. US Navy acknowledged simulator training effectiveness for new airplanes, and allocated 40 flight hours in training simulators and 77 hours in actual F/A-18 airplanes (34% of the whole training hours). US Air Force Air Mobility Command has an even more ambitious plan to replace up to 50% flight hours in training pilots using simulators and other training equipment. It is known that operating costs of flight training simulators are between 5% and 20% of those of actual airplanes, while the average is about 8% [2]. The variable operating costs per hour for aircrafts in operational units and simulators are shown graphically in figure 1 [3]. Another US military study on operating cost reduction of flight training simulators also shows a similar trend, but with different figures [1]. Relative costs of simulated versus actual flight hour are between 3.3% and 14%, while the average ratio is 5.9%. Tested airframes are F-16, FA-18A, P-3C, S-3A, SH-60B, and CH-47 (see figure 1).

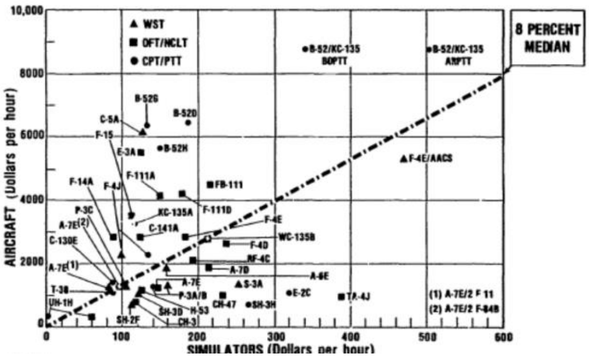


**Fig. 1.** Variable Operating Costs per Hour for 39 Flight Simulators and Aircraft, FY 1980 and FY 1981.

### 2.2 Transfer Effectiveness Ratio (TER)

A standard index explaining benefits of simulator training is TER proposed by Roscoe (1971). TER is a ratio of reduced flight hours or iterations in an actual airplane to the training hours or iterations in a flight simulator:

$$TER = \frac{C-E}{E_{simulator}} \quad (1)$$

where

C = The control group task iterations in an actual airplane
E = The experimental group task iterations in an actual airplane
$E_{simulator}$ = The experimental group task iterations in a simulator

In order to compute a TER of a flight training simulator two training groups are evaluated, where a control group goes through a conventional pilot training process without simulator training, and an experimental group undergoes additional simulator hours and iterations. After completion of flight training, two groups are compared in flight skills. For example, TER of 0.5 implies that 2 flight simulator hours have effects to reduce 1 hour in an actual aircraft. Thus a larger TER indicates more effective in replacing actual flight hours. Comparison studies of TER for military flight simulators show that TER is over 0.33 for 59% of mission flights. Additional information on comparison study of TER can be found at http://www.trainingsystems.org/publications/simulation/roi_effici.cfm. These results can be interpreted as 3 simulator flight hours replace 1 actual flight hours in 59% of whole mission flight training. Orlansky et al analyzed 34 training effectiveness studies [2], and their analysis indicates that flight simulators are consistently effective training tools. The average TER turns out to be 0.48 for 34 training effectiveness studies.

### 2.3 An Optimal Ratio between Actual and Simulator Flight Training Hours

It is a subjective matter to determine a ratio between actual and simulator flight training hours. There exist just limited papers and reports on this issue. For example, Dufaur(2004) set forth that simulation portion of a flight training curriculum shall be 30% in initial, 80% (and more) in familiarization course, 50% during instrument, navigation and terrain flight training (depending upon the mission profile) phases [3]. The criteria to determine these ratios are training progress and training duration as shown in figure 2 [4]. US Marine Corps allocated 43.25% flight hours in simulators out of the total flight hours in 1994. Another optimal ratio study in 2007 with Turkish Army pilots shows that the total ratio will be 49.18% in full flight simulators and 50.82% in real aircrafts (see Table 2). As simulators evolve to replicate the real flight environment closer in years, more use of simulator training occurs.

Korea Aerospace Industries (KAI) manufactures T-50, military jet trainer, and runs a training program for its pilots, where T-50, T-50A (Fighter Derivative), and T-50 export version are trained using real airplanes and a FAA level 7 (or higher) FTD (Flight Training Device) with a projector-screen visual display (see figure 3). As can be seen in Table 3, more sorties are made in the training than those with real T-50 airplanes. For T-50 flight training 18 sorties in the FTD are made within 30 hours, compared with 14 airplane sorties per person. That is, about 56% of the whole training hours is done with the FTD, which is a similar rate to those of US and Turkish Armies.

### 2.4 TER Comparison between FFS (with 6DOF motion) and FTD (without or with limited motion)

As a part of Federal Administration Administration/Volpe Center Flight Simulator Fidelity Requirements Program, training effectiveness of a 6 DOF motion system in FFS (Full Flight Simulator) was investigated. Two groups of pilots were tested in a FFS and a FTD with 1 DOF (Degrees of Freedom) heave motion seat, respectively. In conclusion no apparent proof was identified, showing the advantage of 6 DOF motion in transfer of training [5]. But previous studies on contribution of motion systems in pilot training show that motion systems are effective in training especially when an airplane is affected by unexpected disturbances. Cargo (1979) reports that motion cues enhance pilots' performances in controlling flight simulators under turbulences. Hosman and van der Vaart (1981) also reports motion cues are more effective than visual cues in handling flights under turbulences. Motion platforms enhance pilots' handling capabilities when an engine does not work in multi-engine airplanes (DeBerg, McFarland, and Showalter, 1976). It has been known that motion systems are effective in training of flights with unexpected motions such as turbulences, engine outs, emergencies, and marginal stabilities [6]. In conclusion motion systems, either 6 DOF or 1 DOF, do not contribute much to intended flights of pilots.

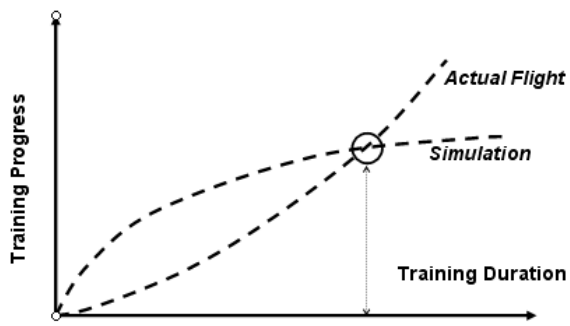


**Fig. 2.** Determining the correct simulation ratio.

**Table 1.** Summary of Flight Hours Ratio in The US Army.

| Aircraft | Aircraft Hours | Sim Hours | Sim Hr. /AC Hr. |
|---|---|---|---|
| F/A-18 | 243 | 95 | .39 |
| AV-8 | 235 | 140 | .60 |
| CH-46 | 131 | 69 | .58 |
| CH-53E | 128 | 20 | .16 |

**Table 2.** Summary of ratios according to training phases in Turkish Army.

| **Flight Training Phases** | **Flying Ratios (%)** | |
|---|---|---|
| | Simulator | Helicopter |
| **Initial Training** | 55 | 45 |
| **Basic Instrument Maneuvers** | 70 | 30 |
| **Radio Instrument Maneuvers** | 90 | 10 |
| **Tactical Flight Training Maneuvers** | 35 | 65 |
| **NVG (Night Vision Goggle) Phase Maneuvers** | 35 | 65 |
| **Different Maneuvers of AS-532** | 60 | 40 |
| **Different Maneuvers of US-60** | 75 | 25 |
| **Different Maneuvers of AH-1W/p** | 60 | 40 |

**Fig. 3.** A pilot demonstrates a simulator of the T-50 advanced jet trainer at the First Fighter Wing of South Korean air force in Gwangju

**Table 3.** Syllabus of Korea Aerospace Industries for T-50 Training (by Courtesy of KAI).

| **Classes** | **Duration (weeks)** | **Hours or Sorties** | **Lessons** |
|---|---|---|---|
| **Classroom Lessons** | 3 | 100 Hr | Aircraft System, G-Test T.0-1, Regional Flight Procedure |
| **T-50 Flight Training** | 7 | 30 Hr | Normal/Emergency Procedures, Aerial Operation, IFR, Regional Flight Procedure, etc. |
| | | Simulator 18 sorties per person | |
| | | Airplane 14 sorties per person | |
| **TA-50 Flight Training** | 10 | 30 Hr | Flight Safety, Normal/Regional Flight Procedures, BFM, TI, etc |
| | | Simulator 13 sorties per person | |
| | | Airplane 11 sorties per person | |
| **Flight Training T-50 Export Versions** | 9 | 25 Hr | T.0-1 Regional Flight Procedures, Checklist |
| | | 10 Hr | TR, BFM, TI, SA Phase Briefing FCF Phases Briefing |

## 3 Simulator Training Hours and Cost Reduction Effects

### 3.1 Permissible FSTD Training Hours by FAA

The part numbers refer to the applicable regulations of FAA, 14 CFR (Code of Federal Regulations) 61 and 14 CFR 141. More information on FAA Regulation can be found at https://www.faa.gov/regulations_policies/faa_regulations/ [12]. A flight school has the option of teaching under either part. Part 61 is the simpler system. Part 141 gives the school the opportunity to graduate students with fewer hours, but it places more restrictions on the training. The FAA expects the same performance standards in order to award a certificate or rating. But FAA is required to oversee the operations of a part 141 school to a much higher degree. All the records are reviewed on a regular basis for compliance and completeness. Par 61 requires more flight hours than Part 141 while the FAA control is less strict. For example, Part 61 requires 2.5 FSTD hours toward a private pilot certificate with 40 total flight hours while Part 141 enforces 7 FSTD hours out of 35 total flight training hours. For a commercial pilot certificate Part 61 requires maximum 50 FSTD hours in 150 total flight hours, while Part 141 requires 36 and 120 hours, respectively. FAA allows training hours in FSTD (Flight Simulation Training Devices) up to 50% of the total required flight hours to earn certificates or ratings in civil pilot schools, and the relevant regulations are described in 14 CFR Part 141. The Part 141's FSTD hours are summarized in Table 3.

### 3.2 FSTDs and Airplanes in Civil Airlines and ROK Air Force

It is a typical question for aircraft operators to determine how many simulators are desirable. Depending on the types of simulator operators, trainees, economic status, and so on, appropriate ratios of simulators to actual airplanes may vary. One way to answer this question is to investigate the practices of commercial airlines and military services. Unfortunately, information on fleet sizes of military services is difficult to obtain. The following analysis is very limited, but the information shall be helpful for training schools, centers, military services to determine the number of simulators to be purchased in the future. Most civil transport airlines operate FSTD with ratios between 1:10 and 1:20 (FSTD : Airplanes) as summarized in Table 5. Additional Information about ratio of flight hours in FSTD to aircraft of airline's can be found Planespotters.net, Airfleets.net, Wild Story, Military Simulator Census and Civil Simulator Census [10,11]. ROK (Republic of Korea) Air Force has an even higher FSTD ratio of 8.3:1 than those of civil airlines.

### 3.3 Necessary Quantity of FSTD and Cost Reduction Analysis

There are so many factors to be considered in determining a necessary quantity of FSTD and relevant operating cost reduction. For a military service the following operating conditions are assumed:

- Permissible Flight Hours per Year
  : 100 airplanes x 20 hours(permissible flight hours per month) x 12 months x 0.5 (Operation Ratio for Training) = 12,000 hours
- Simulator Training Hours per Year
  : 12,000 hours (Permissible Flight Hours per Year) x **R** (Simulator Training Ratio) = 12,000R hours
- Operation Hours of a Simulator per Year
  - ✓ Daily Operation Hours: **D** hours
  - ✓ Operation Days: 200 days
  - ✓ Operation Hours of a Simulator per Year: D hours x 200 days = 200D hours

Then the quantity of necessary simulators can be calculated as follows

- Number of Necessary Simulators = Simulator Training Hours per Year / Operation Hours of a Simulator per Year = 12,000R/200D = 60R/D
  eg) If R=0.3, D=7, then the number of necessary simulators becomes 2.57.

Assuming 2.5 pilots per airplane, the FSTD hours per pilot can be computed as follows

- 2.5 Pilots per airplane x 100 airplanes = 250 pilots
- Average Simulator Training Hours per Pilot: 12,000R hours/250 pilots x 2 (2 Seats per Simulator) = 96R hours
- Actual Flight Hours per Pilot: 12,000 hour/250 pilots x 2 (2 Seats per Airplane)= 96 hours

With the above conditions the following case studies are performed:

- Case Study 1: FAR Part 141 requires minimum 120 flight hours for a commercial pilot certificate, where up to 36 FSTD hours are allowed. Then 24 hours have to be trained in FSTD. If R=0.3, then 28.8 (96 x 0.3) hours come out of FSTD to exceed the minimum flight hour requirements, satisfying the limit of 36 FSTD hours.
- Case Study 2: FAR Part 141 requires minimum 115 flight hours for a rotorcraft pilot certificate, where up to 25 FSTD hours are allowed. Then 19 hours have to be trained in FSTD. If R=0.22, then 21.1 (96 x 0.22) hours come out of FSTD to exceed the minimum flight hour requirements, satisfying the limit of 25 FSTD hours.

Experimental results described in this paper cannot be generalized, because the training effects may depend on such factors as simulator specifications, number of trainees, types of airplanes, and so on. Maintaining equivalent training effects, cost reduction ratios can be formularized as

$$\text{Cost Reduction Ratio} = R \times (1 - E / TER) \quad (2)$$

where E = operating cost ratio of simulators to actual airplanes, and R = Simulator Training Ratio. If R= 0.5, TER=0.33, and E= 0.08, then the cost reduction becomes 38% of actual airplane training. . If R= 0.3, TER=0.33, and E= 0.08, then the cost reduction becomes 22.8% of actual airplane training. Under FAR part 61, 25 hours are allowed towards an ATP (Airline Transport Pilot). Then R=1.0, and 76% (= 1 – 0.08 x 3) of training cost is reduced compared with actual airplane training.

**Table 4.** Permissible FSTD Training Hours in FAR Part 141.

| Pilot Certificates | Minimum Flight Hours | Maximum FSTD Hours | Ratios of Flight Hours in FSTD to Aircraft |
|---|---|---|---|
| **Private pilot certificate** | 35 | 7 | 0.20 |
| **Instrument ratio** | 35 | 17 | 0.49 |
| **Commercial pilot certificate** | 120 | 36 | 0.30 |
| **Rotorcraft pilot certificate** | 115 | 25 | 0.22 |
| **Multi-engine rating** | 25 | 10.5 | 0.42 |
| **ATP certificate** | 25 | 12.5 | 0.50 |
| **Flight instructor certificate** | 25 | 2.5 | 0.10 |
| **Instrument flight instructor rating** | 15 | 1.5 | 0.10 |

**Table 5**. FSTDs and Airplanes in Civil Airlines and ROK Air Force.

| Airline/Military Service | Number of Aircrafts | Number of FSTD | Ratios of Aircrafts to FSTD | Reference Year |
|---|---|---|---|---|
| **Korean Air** | 165 | 8 FFS | 20.6 : 1 | 2017 |
| **Asiana Airlines** | 84 | 5 FFS | 168 : 1 | 2016 |
| **American Airlines** | 956 | 44 FFS | 21.7 : FFS | 2016 |
| | | 14 FTD | 16.5 : 1 FSTD | |
| **Air France** | 221 | 18 FFS | 12.3 : 1 FFS | 2016 |
| | | 2 FTD | 11.1 : 1 FSTD | |
| **ROK Air Force (F-16 Only)** | 166 | 20 FSTD | 8.3 : 1 | 2015 |

## 4 Conclusions

This study is to answer questions regarding appropriate training hours, transfer effectiveness, and cost reduction effects of airplane simulators, which are typical concerns of simulator customers and operators. Technical papers and reports on simulator training effectiveness are reviewed and analyzed as well as relevant regulations of FAA. The papers and reports show similar trends with different figures, which is inherent nature of experimental studies. From the conservative perspectives, the following observations are summarized:

- Mean simulator operating cost per hour is 8% of actual airplanes.
- Typical TER (Transfer Effective Ratio) is over 0.33.
- Motion platforms contribute to transfer of training for unintended maneuvers due to turbulences and engine outs.
- Most training centers and schools, either military or civil, allocate 30%~50% training hours in simulators, which agrees to FAR Part 61 and 141.
- Most civil transport airlines operate FSTD with ratios between 1:10 and 1:20 (FSTD: Airplanes).

The primary contribution of this study is to formulate rules to determine appropriate simulator training hours and cost reduction ratios based on the previous works on TER reviewed in this paper. Cases studies show reasonable results compared with present practices in civil and military training schools. As simulation technologies evolve further, TER and simulator training ratio shall become larger, which agrees to the FAA vision on simulator training. Then the dream of zero-time real flight in the simulation community might come closer.

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