Mission Based Combat Simulator Selection

Adnan Aygündüz, Eyyüp Çelik
Ankara, Turkey
aygunduz@hotmail.com, cider31@gmail.com

ABSTRACT

Combat pilot training is a risky and costly requirement. Therefore, flight simulators are being used for decades to improve quality of the training and lower the costs. However, simulators could have a significant cost as the fidelity level increases. It is apparent that selection of right fidelity simulator would contribute to reducing the price and improving the training effectiveness. Therefore the relationship between the training requirements and the minimum level of fidelity that fulfills the training requirements needs to be investigated. Literature survey showed that little work was done in the area of simulator selection based on mission skills requirements. This study follows a two step methodology by first determining the minimum level of fidelity required for various mission skills than matching these requirements with various common simulator types to determine which simulators are able to fulfill fidelity requirements for each mission skill. In the first step an expert user group is utilized to determine main factors contributing to the fidelity in simulators then various common combat aircraft simulators are assessed against the factors determined above. Then mission skills are determined using a combination of mission types and singular skills common across various mission types. In the second step, twenty F-16 instructor pilots were surveyed to determine the minimum fidelity requirements for each mission skills. Then, survey results are combined with earlier findings to determine which simulator types are required as a minimum to fulfill training requirements for each mission skill. The results and trends are discussed in conclusion. In scope, this study focuses on basic fighter training environment and the results can provide basis for simulator selection and structuring the training curriculum.

ABOUT THE AUTHORS

Author1 Adnan Aygündüz is a graduate of Turkish Air Force Academy with an undergraduate degree in Electronics Engineering in 2001. At the same year he was commissioned as an officer in Turkish Air Force and started pilot training. He has served in various F-16 squadrons. He got his first masters degree in International Relations in 2007 from University of Selcuk in Konya. He has attended the Turkish Air War College and graduated with a master's degree in International Relations in 2010. He is an F-16 instructor pilot with over 1500 flight hours in the Fighting Falcon. He has worked in the new generation F-16 simulators project for three years.

Author2 Eyyüp Çelik is a graduate of United States Air Force Academy with an undergraduate degree in Aeronautical Engineering in 2001. At the same year he was commissioned as an officer in Turkish Air Force and started pilot training. After various flying assignments, he has got his masters degree at University of Houston in Aerospace Engineering focusing on control and dynamics in 2008. He has attended the Turkish Air War College and graduated with a master's degree in International Relations in 2011. He is an F-16 instructor pilot with over 1000 flight hours in the Fighting Falcon.

Mission Based Combat Simulator Selection

Adnan Aygündüz, Eyyüp Çelik
Ankara, Turkey
aygunduz@hotmail.com, cider31@gmail.com

INTRODUCTION

Combat pilot training is a risky and costly requirement. It is no surprise that simulators have been used for decades to improve the quality of training, reduce risk and monetary costs. Early simulators were less ambitious, aiming to simulate a particular aspect of the flight training such as instruments training. However as the computing and imaging technology advanced, new simulators came to life that are able to simulate almost all aspects of a fighter sortie. Unfortunately these advanced simulators are very costly and therefore should be used in training where most benefit can be achieved. It has become a common theme among world air forces to use a wide range of simulators for various aspects of the training. This study aims to provide a guide in determining the simulator requirements in combat pilot training by matching the mission skills with types of simulators. In scope, this study focuses on basic fighter training environment and the results can provide basis for simulator selection and structuring the training curriculum.

Fidelity Discussion

Fidelity is one of the most important concepts in simulation research. Although there are various definitions, it is not possible to find one agreed definition. Rehmann's assertion that "the concept of fidelity relates to the degree to which the characteristics of a flight simulator match those of the real airplane" carries the most essential characteristics of the various definitions (Rehmann, Mitman, & Reynolds, 1995, p. 8), (Noble, 2002), (Duncan, 2006) and is the most appropriate one for the aims of this study.

Perhaps it is as important as the definition to realize that fidelity is accepted to have various types. Operational, physical, functional, equipment, environmental, psychological, task, functional, content, workload, motivational, selective, dynamic, database and temporal fidelity are some of the types mentioned in various studies (Thomas, 2003), (Rehmann, Mitman, & Reynolds, 1995), (Duncan, 2006). Although each of these types are better suited for a certain research objective, operational fidelity and task fidelity are the ones that best suit the combat training simulators, as the final objective is to train the individuals for the certain tasks they would perform in operational environment. Therefore, for the purposes of this study, fidelity refers to the degree simulator is able to imitate the tasks and operational environment.

It might be intuitive to think that higher fidelity results in better learning. But various studies have shown that such direct relationship does not exist. Higher fidelity levels than required might result in lower transfer of learning. Dahlstrom et.al. argue that there is a disconnect between the fidelity of the simulator and its "validity (how the skills it develops map on to situations in the target environment)" (Dahlstrom, Dekker, Van Winsen, & Nyce, 2009, p. 312). He further argues that generic problem-solving skills such as, sharing knowledge, making and following up on plans, dividing work are better developed through lower fidelity simulators. Carretta and Dunlap reviewed studies relating to simulator learning and identified that learning increases as the number of simulated sorties increases, but this gain levels off after approximately 25 missions (Carretta & Dunlap, 1998). They further identified that; several studies indicate successful transfer may not require high-fidelity simulators or whole-task training, thus reducing simulator development costs. Rehmann points out that high fidelity environment might provide distraction and might introduce extraneous factors to influence behavior (Rehmann, Mitman, & Reynolds, 1995). Such effects would not be desired if the focus of training or research is on a specific task/area. Noble researched the relationship between fidelity and learning in aviation training and assessment, in which he argues that total fidelity (higher the fidelity, better the transfer of learning) concept is better suited for training and assessment of expert pilots. He argues that novice pilots could be overwhelmed with total fidelity. Thus according to Noble, learning stage of the student plays a major role in the relationship between degree of fidelity and transfer of learning (Noble, 2002). Although without empirical evidence, Noble's views are supported by aviation experts (Schank, Thie, Graf, Beel, & Sollinger, 2002).

Another important aspect of the fidelity discussion is cost. Duncan argues that as a general rule, increase in fidelity will result in an exponential amount of increase in cost (Duncan, 2006). Therefore unless an increase in fidelity would result in an exponential amount of increase in learning, the high fidelity/high cost may not be justified.

The discussion above shows that there is no direct proportional relationship between fidelity and learning. The cost discussion highlights the fidelity-cost dilemma and introduces the practical reason to use low fidelity simulators if possible. When these two arguments are combined, it can be deducted that minimum fidelity requirements for training requirements should be identified so that transfer of learning can be maximized and cost can be minimized.

METHODOLOGY

In order to match the simulators with various fidelity, against training requirements this research follows the steps below.

1. Determine the main factors contributing to the fidelity in simulators
2. Assess various common combat aircraft simulators against the factors determined above
3. Determine the mission skills set for combat pilot training
4. Determine the minimum fidelity requirements for mission skills set above
5. Conduct a comparison between the minimum fidelity requirements and combat training simulator fidelity

Main Factors Contributing to Fidelity

As discussed above, there are numerous factors effecting fidelity of a simulator. Some of these factors are internal to the simulator and its subsystems, while factors such as instructor, curriculum etc. may be examples of external factors in assessing the fidelity levels of a simulator (Prasad, Schrage, Lewis, & Wolfe, Performance and Handling Qualities Criteria for Low Cost Real Time Rotorcraft Simulators - A Methodology Development, 1991). In order to make an objective assessment, this study is concerned only on the internal factors that can be directly related to the simulator and its subsystems. Prasad et.al. determined ten subsystems can generally be used to define a simulator system. This study resorted to subject matter experts to determine the principal attributes of simulators, which contribute to fidelity. Subject matter experts from F-16 Simulator Training Center in Turkish Air Force were interviewed and seven principal attributes with associated degrees of fidelity were commonly accepted. Table 1 describes the results achieved.

Table 1. Principal Attributes of Combat Aircraft Simulators and Associated Degree of Fidelity

Visual (Out The Window - OTW)	
Computer Screens	Usually achieved through single computer screens
≤135° Horizontal FOV	Usually achieved through multiple computer screens arranged in the forward quarter
135-180° Horizontal FOV	Usually consists of a semi-dome like structure with multiple projectors
180-360° Dome	Dome like structure with multiple projectors
Motion	
No	Stationary cockpit
G Seat	Simulates G environment by small movement in the cockpit, g-suit inflation and harness tensioning
3 DOF	Rotation around 3 axis
Pilot Vehicle Interface (PVI)	
Partially Similar	Cockpit usually consists of stick, throttle and single touchscreen. Interface to menus are through single touchscreen. Avionics are modeled. Not all cockpit switches are modeled.
Similar	Cockpit usually consists of stick, throttle and multiple touchscreen interfaces around the pilot. All cockpit switches and functionalities are simulated through

	touchscreens.
Same	Cockpit has the same physical interfaces with aircraft, including NVG compatibility
Aircraft Performance Modeling	
Partially Accurate	Simplified modeling used parameters such as flight characteristics and fuel consumption might have small differences with real life
Accurate	Virtually no difference between models and real world
Weapons Modeling	
Simplified	Simplified modeling used for parameters such as max range, geometry, g etc.
Accurate	Virtually no difference between weapon models and real world
Environmental Conditions	
Partial Capability	It is possible to simulate visibility, night, clouds, and rain. Wind and gusts are modeled in a rough estimation.
All Weather	It is possible to simulate visibility, night, clouds and rain. Wind and gusts are modeled accurately.
All Weather + NVG	Visibility, night, clouds, rain, wind and gusts are simulated accurately including night vision goggles.
Link	
Single ship	No link capability
Multiple Linked Simulators	Link capability to other simulators in the same compound including different types
Multiple Linked Simulators at Different Geo-location	Link capability to other simulators at different geo-locations including different types

When the results are compared to survey results of Prasad et.al (Prasad, Schrage, Lewis, & Wolfe, Performance and Handling Qualities Criteria for Low Cost Real Time Rotorcraft Simulators - A Methodology Development, 1991), it is realized that some attributes such as audio, control system, ground handling, mission equipment, system latency did not appear in the results of this study and additional attributes such as link are considered. Technology advances since Prasad study in 1991 is the reasons that account for these differences. Technological advances negated some attributes such as sound, control systems, ground handling, mission equipment and system latency as all current simulators have very high fidelity in these areas and virtually no system latency. Also technological advances have allowed new capabilities such as link.

Assessing Common Combat Aircraft Simulators

There are many different combat aircraft simulators in the world. In fact as a common practice all combat aircraft have one or more type of simulators used for training pilots. There are various classification of simulators such as the one used by Federal Aviation Industry in United States and Civil Aviation Authority in United Kingdom.

However, these classifications do not serve well for the purpose of this study, as simulators for civil aircraft have fundamentally differing qualities. For example 3 DOF motion or 6 DOF motion is very common in civil aviation simulators while it is very demanding to simulate even 3 DOF in combat aircraft due to high angular freedom of combat aircraft.

For the purposes of this study, it is possible to group the various simulator types used in combat aircraft training into five categories. Furthermore, the principal attributes of simulators can be assessed in terms of the factors determined above.

Table 2 depicts the results of this assessment. Subject matter experts were utilized in both grouping and assessment phases. It should be noted that, this table represents the common attributes of simulator types currently employed in the world and possibly there are simulators that differ from these in one or more areas.

Table 2. Classification and Assessment of Common Combat Aircraft Simulators

	Common Criteria						
	Visual	**Motion**	**PVI**	**Aircraft Performance Modeling**	**Weapons Modeling**	**Environmental Conditions**	**Link**
3DOF Full Mission Simulators	180-360°, dome	G Seat	Same	Accurate	Accurate	All Weather + NVG	Linked /Single
Full Mission Simulators	180-360°, dome	G Seat	Same	Accurate	Accurate	All Weather + NVG	Linked /Single
Mission Trainer	135-180° FOV	No motion	Same	Accurate	Accurate	All weather	Linked /Single
Weapon and Tactics Trainers	≤135° FOV	No motion	Similar	Accurate	Accurate	All weather	Linked /Single
PC Based Desktop Trainers	Computer Screens	No motion	Partially Similar	Partially Accurate	Simplified	Partial Capability	Linked /Single

Determining Mission Skills

There have been studies aiming to list the critical skills required for a mission of which Air Force Research Labs study on Mission Essential Competencies (MEC) is the most notable one (Symon, France, Bell, & Winston , 2006). MEC study lists mission essential competencies, supporting competencies, knowledge and skills for a particular mission type. Schank et.al. utilize measures of performance, which resembles MEC (Schank, Thie, Graf, Beel, & Sollinger, 2002). Although these approaches would be beneficial in developing detailed syllabus events, they are too detailed for the more holistic approach followed in this study and also would present difficulties regarding survey method used in later steps.

In order to determine the mission skills to be validated, F-16 training syllabi from two different countries are analyzed. The training syllabi list the sortie requirements and key events in each sortie. The approach taken follows the key mission skills rather than mission type approach. Mission types might require the same basic skill, but using this skill in different circumstances would result in different mission types. For example, intercept is a mission skill, and this skill is used in various missions such as sweep, combat air patrol, escort etc. Although the mission skill is same, different circumstances such as offensive/defensive, results in different mission types. Since these factors are not distinguishing items for a simulator, evaluating the requirements for mission skills rather than mission types would result in more relevant output.

Distinct mission skills throughout the whole spectrum of fighter training are determined by an expert group consisting of instructors in the F-16 training squadron, in Turkey. Table 3 below lists the resulting mission skills set.

Table 3. Mission Skills Set For Combat Pilot Training

Mission Skills	Comments
Ground Procedures	Cockpit familiarization, starting engine, avionics setups, before takeoff checks, taxi procedures etc.
Basic Flying Skills	Takeoff, landing, navigation
Emergency Procedures	-
Instrument Flying	-
Intercept	IR and BVR 2v2, 2v4, 4v4, etc. Also representative of Sweep, Escort etc. mission types.

Air Combat Maneuvers	This mission skill covers within visual range engagements to include Basic Fighter Maneuvers and Air Combat Tactics.
Dive/Level Bombing	Unguided/GP munitions employment
Smart Weapons Delivery	Self-guided and precision attack munitions
Low Altitude Training	-
Close Air Support	-
Armed Tactical Reconnaissance	-
Air-to-Air Refueling	Precontact, contact and emergency procedures
Night Vision Goggles (NVG)	Could be incorporated into any of the mission set above. Requires NVG compatible environment.

Determining Minimum Fidelity Requirements For Mission Skills

The minimum fidelity requirements (in areas depicted in table 1) need to be determined for each mission skill. These represents the minimum requirements that a simulator needs to possess in order to provide effective training for the respective mission skill. This was achieved through surveying twenty F-16 instructor pilots. The survey starts with an introductory part, which explains the aim of this study and guidelines on filling out the survey. It is emphasized that what they are assessing is the absolute minimum requirements for the skills to be achieved. Therefore it is made clear that, the requirements are not for the best simulator, but rather it is for the minimum level needed in order to achieve effective training. It is also emphasized that when determining the minimum requirements, focus should be on training requirements for basic fighter training as different experience levels might have different requirements. Through consolidation of survey results it was possible to produce a table, which shows the minimum requirements for the mission skills.

Table 4. Survey Results for Minimum Fidelity Requirement for Mission Skills

	Visual (OTW)	Motion	PVI	Aircraft Performance Modeling	Weapons Modeling	Environmental Conditions	Link
Ground Procedures	Computer Screens	No	Same	Partially Accurate	Simplified	Partial Capability	Single ship
Basic Flying Skills	135-180° FOV	No	Same	Accurate	Simplified	Partial Capability	Single ship
Emergency Procedures	≤135° FOV	No	Same	Accurate	Simplified	Partial Capability	Single ship
Instrument Flying	Computer Screens	No	Partially Similar	Partially Accurate	Simplified	Partial Capability	Single ship
Intercept	≤135° FOV	No	Partially Similar	Partially Accurate	Accurate	Partial Capability	Linked Simulators
Air Combat Maneuvers	180-360° Dome	No	Similar	Accurate	Accurate	Partial Capability	Linked Simulators
Level/Dive Bombing	135-180° FOV	No	Partially Similar	Accurate	Accurate	Partial Capability	Single ship
Smart Weapons Delivery	Computer Screens	No	Partially Similar	Partially Accurate	Simplified	Partial Capability	Linked Simulators
Low Altitude Training	≤135° FOV	No	Similar	Partially Accurate	Simplified	Partial Capability	Linked Simulators
Close Air Support	135-180° FOV	No	Similar	Partially Accurate	Accurate	Partial Capability	Linked Simulators
Armed Tactical Recce	135-180° FOV	No	Similar	Partially Accurate	Accurate	Partial Capability	Linked Simulators
Air-to-Air Refueling	135-180° FOV	No	Similar	Accurate	Simplified	Partial Capability	Single ship
Night Vision Goggles	180-360° Dome	No	Same	Accurate	Simplified	All Weather+NVG	Linked Simulators

Trends and analysis of the results are discussed below for each criteria:

Visual:

The results showed a fairly balance distribution with 135-180° FOV being able to fulfill approximately 40% of the mission skills. Air combat maneuvers, and night vision goggles training are the mission types that require higher (dome type) visual coverage. Computer screens have been selected for ground procedures, instrument flying and smart weapons delivery.

Motion:

Motion capability is not deemed required in any of the mission types. But, it should be mentioned that, on average one third of the surveyors defined G-Seat as a requirement for most of the mission types.

Pilot Vehicle Interface:

PVI is another criterion with balanced requirements across all three fidelity levels. There is a correlation between the fidelity level requirements of visual and PVI. Those mission skills that have high level of fidelity tend to also have higher fidelity requirements in PVI. Survey participants indicated that, “partially similar” level PVI might be appropriate for experienced pilots in some mission types, but basic fighter training (focus of this study) requires a higher fidelity PVI.

Aircraft Performance and Weapons Modeling:

In both aircraft and weapons modeling, the survey results showed an emphasis on high fidelity modeling. It is important to note that aircraft performance modeling on average required higher fidelity than weapons modeling.

Environmental Conditions:

In environmental conditions, almost all mission skills require partial weather capability as a minimum.

Link:

In link requirements, the results showed an emphasis on linked simulators. It is worth to note that even the mission types such as close air support, armed reconnaissance, low altitude training was deemed to require linked simulators. Results also showed no interest in linking with different geo-locations (other simulator centers). These results might be attributed to the training environment in which formation position and situational awareness on the formation members are important emphasis points.

Comparison Between The Minimum Fidelity Requirements And Combat Training Simulator Fidelity

A comparison between the fidelity requirements determined in the previous section and fidelity traits of the five simulator types described above is conducted to determine what type of simulator can be used for each mission skill. In this comparison a cookie cutter approach is used in which a simulator type is determined to be appropriate for a mission skill only its fidelity traits matches or exceeds those that are required by the respective mission skill. The resultant table is shown below.

Table 5: Mission Skills and Simulator Type Fulfillment Comparison Results

	3 DOF Full Mission Simulators	Full Mission Simulators	Mission Trainer	Weapon and Tactics Trainers	PC Based Desktop Trainers
Ground Procedures	+	+	+	-	-
Basic Flying Skills	+	+	+	-	-
Emergency Procedures	+	+	+	-	-
Instrument Flying	+	+	+	+	+
Intercept	+	+	+	+	-
Air Combat Man.	+	+	-	-	-
Dive Bombing	+	+	+	-	-
Smart Weapons Delivery	+	+	+	+	+

Low Altitude Training	+	+	+	+	-
Close Air Support	+	+	+	-	-
Armed Tactical Recce	+	+	+	-	-
Air-to-Air Refueling	+	+	+	-	-
Night Vision Goggles	+	+	-	-	-

CONCLUSION

As it is important to specify the level of experience the simulator users are assumed to have, the surveys used in this study explicitly mentioned that "basic fighter training" students are to be taken as the focus in determining fidelity requirements. Surveyors expressed that the requirements they determined would differ, if the focus was on mission requalification or mission rehearsal including more experienced pilots, rather than basic fighter training.

This study has two main areas of results. First one is the relationship between the mission skills and associated minimum fidelity requirements. The results have a fairly balanced distribution with a slight tendency to favor the high end fidelity requirements. Survey participants indicated that, in some areas lower fidelity requirements might be appropriate for experienced pilots, but basic fighter training requires a higher fidelity PVI. On the link requirements, it is worth to note that even the mission types such as close air support, armed reconnaissance, low altitude training was deemed to require linked simulators. Results showed no interest in linking with different geo-locations (other simulator centers). These results might be attributed to the training environment in which formation position and situational awareness on the formation members are important emphasis points.

Mission skills requirement and simulator types' comparison is the second main area of results in this paper. The results show that Mission Trainer is able to fulfill requirements for all mission skills except air combat maneuvers and night vision training. These mission skills require full mission simulators due to higher visual coverage requirements. Weapons and tactics trainers are able to fulfill four mission skills mainly due to lacking visual coverage. PC based desktop trainers are able to fulfill instrument flying and smart weapons delivery mission skills.

In conclusion, this study has proposed and explored a methodology in matching simulator types with required mission skills. The methodology could be applied to various areas of simulator use (training, mission rehearsal, updating currency in mission types etc). The benefits include better matching of mission skills requirement to simulator types, which would result in increased transfer of learning, decreased cost of simulators and guidance in syllabus development.

ACKNOWLEDGEMENTS

Firstly, we would like to thank our families for their support in our pursuits. Secondly we would like to thank all the F-16 instructor pilots who took the time to fill out the survey and reflect their hard earned experiences. The views expressed here are solely those of the authors in their private capacity and do not in any way represent the views of the Turkish Air Force.

REFERENCES

Bernard, M. (2012). Real Learning Through Flight Simulation. *FAA Safety Briefing, September*, pp. 8-10.

Carretta, T. R., & Dunlap, R. (1998). *Transfer of Training Effectiveness In Flight Simulation: 1986 to 1996.* Mesa: United States Air Force Research Laboratory.

Dahlstrom, N., Dekker, S., Van Winsen, R., & Nyce, J. (2009). Fidelity and Validity of Simulator Training. *Theoretical Issues In Ergonomics Science, 10*, pp. 305-314.

Duncan, J. (2006). Fidelity Versus Cost and Its Effect On Modeling And Simulation. *12th ICCRTS.* Suffolk.

Noble, C. (2002). The Relationship Between Fidelity and Learning In Aviation Training and Assessment. *Journal of Air Transportation, 7*.

Perey, A. R., & Mania, K. (2004). Flight Simulation: Research Challenges and Flight Crew Assessment of Fidelity. *International Conference on Virtual Reality Continuum and its Applications in Industry* (pp. 261-268). Nanyang: ACM.
Prasad, J. V., Schrage, D. P., Lewis, W. D., & Wolfe, D. (1991). Performance and Handling Qualities Criteria for Low Cost Real Time Rotorcraft Simulators - A Methodology Development. *Proceedings of the 47th Annual Forum of the American Helicopter Society.* Alexandria: American Helicopter Society.
Rehmann, A. J., Mitman, R., & Reynolds, M. (1995). *A Handbook of Flight Simulation Fidelity Requirements for Human Factors Research.* US Department of Transportation, Federal Aviation Administration. Springfield: National Technical Information Service.
Schank, J., Thie, H., Graf, C. M., Beel, J., & Sollinger, J. (2002). *Finding The Right Balance.* Santa Monica: RAND Corp.
Symon, S., France, M., Bell, J., & Winston , B. (2006). *Linking Knowledge and Skills to Mission Essential Competency Based Syllabus Development For Distributed Mission Operations.* Air Force Research Laboratory, Mesa AZ.
Thomas, M. J. (2003). Operational Fidelity in Simulation-Based Training: The Use of Data From Threat and Error Management Analysis in Instructional Systems Design. *SimTECT* (pp. 91-95). Adelaide: University of South Australia.