EFFECTIVENESS OF FLIGHT SIMULATION IN TRAINING KC-10 PILOTS IN RECEIVER REFUELING

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ABSTRACT

This study examines the transfer of training for pilots from the simulator to the aircraft for the task of receiver refueling. Receiver refueling requires the receiver pilot to position the aircraft behind the tanker aircraft and maintain the position while taking on fuel. This task is trained in the KC-10 flight simulator (six degree-freedom of motion system and day/dusk/night computer generated image visual system) during Pilot Initial Qualification and Refresher training. The investigation used student performance scores from both the simulator and aircraft for like conditions. Pilots completed critiques containing questions regarding the fidelity and usability of the simulator visual and motion system as compared to the actual aircraft and real-world refueling environment. The results showed a positive transfer of training with implications for the training of air refueling and the configuration of training devices.

INTRODUCTION

The study described in this report is an effort to determine whether simulator training of the KC-10 receiver refueling task transfers positively to task performance in the aircraft. A positive transfer of receiver refueling skills would suggest that less aircraft training time is needed to train a student to proficiency in receiver refueling. A reduction of aircraft training time would result in increased safety and decreased costs. There are also implications regarding the design, configuration and allocation of flight simulation devices.

The effectiveness of advanced flight simulation technology in training qualified pilots in those skills needed to transition to a new type of aircraft has been demonstrated repeatedly by the military and major air carriers over the past decade. The effectiveness of this technology in producing a positive transfer of training from the simulator to the aircraft is considered reliable enough that the Federal Aviation Administration has modified its regulations governing the acquisition of type ratings. A transitioning pilot may receive all of his training on a new aircraft type in a properly certified simulator-based training program (FAA Reg. Part 121.14, App. H.). Under contract to the United States Air Force, McDonnell Douglas Training Systems, Inc. (MDTSI) has applied this advanced simulation technology to the task of training KC-10 pilots. MDTSI has undertaken to produce fully qualified pilots with minimum use of aircraft flight time dedicated for training. This goal applies to all KC-10 flying tasks except air refueling as the receiver aircraft; i.e., where the pilot takes on fuel from another tanker aircraft. The receiver refueling task requires the receiver pilot to establish a precontact position approximately 50 feet from the tanker refueling boom. After clearance is received from the tanker boom operator, the receiver pilot moves to the contact position and maintains this position; at the same time the boom operator inserts the boom nozzle into the receiver's air refueling receptacle and fuel is transferred. Maintenance of the contact position is aided by Pilot Director Indicators (PDI's) located on the underside of the tanker aircraft (either KC-135 or KC-10). The PDI's signal to the receiver pilot the corrections needed to maintain contact. For example, the PDI's may signal the receiver pilot to move back and down. When the receiver is in position, the green PDI's are illuminated and the receiver is "in the green". Few pilots rely exclusively on the PDI's and use other visual cues to maintain the contact position. Pilots must be able to perform without PDI lights for contingency operations or if lights are not operating.

The contractor-operated training system has attempted to reduce the number of aircraft training flights required to initially qualify from 10 to 12 to 5 to 6. This reduction in training time has been offset by simulating the receiver refueling task in the KC-10 flight simulator, a high-fidelity advanced flight simulator whose math model and computer-generated-imagery (CGI) visual system have been engineered to accommodate the training requirements of this task.

METHODOLOGY

Overview

This study was performed within the framework of an operational training system, for which no past or concurrent training alternative exists. The historical data on those few pilots trained solely in the KC-10 aircraft on the receiver refueling task was not available. Therefore, the study design is focused on repeated measures of pilot trainee performance of the receiver refueling task in the simulator and the aircraft. The study does not attempt to investigate or control intervening variables such as variations in instructor techniques or instructor emphasis on areas of student weakness. These factors may be operative in KC-10 training but are not susceptible to control.

The study investigates the transfer of receiver refueling performance from the simulator to the aircraft by testing for significant differences in scores on the last simulator receiver refueling mission and the first receiver refueling mission of like conditions to occur in the aircraft. Four conditions of receiver refueling addressed the type of tanker aircraft (KC-10 or KC-135) and time refueling occurred (day or night); thus, the conditions were KC-10 Day, KC-10 Night, KC-135 Day, and KC-135 Night.

Although determinating the existence of a transfer of training is feasible under this approach, the critical factors affecting transfer are not identified. In an effort to identify for subsequent research efforts those elements of simulator training that affect the transfer of training to the aircraft, descriptive data are gathered from students through questionnaires. Students are asked to identify which elements of their simulator training are helpful or not helpful in learning the receiver refueling task. Of particular interest are the visual cues used in both the simulator and the aircraft, the differences in the visual cues utilized between the two training environments, and the quantity and quality of suitable visual cues presented by the simulator visual system. These data help determine the existence or nonexistence of a transfer effect and indicate productive directions for future research.

Subjects

Both KC-10 Initial Qualification and Refresher pilots were subjects to this study. The exact number of subjects used in each analysis varies and is reported in the applicable section of Data Collection, Analysis, and Results. Initial Qualification pilots are those pilots qualifying for the first time in a KC-10 and may or may not have prior receiver refueling experience in other aircraft. (Each student's previous experience is described in the analysis of student background data.) Refresher pilots have previously been through Initial Qualification, received training and conducted operational missions in the aircraft and have returned for required refresher training. The pilots in Refresher training served as a source of information regarding simulated receiver refueling as viewed by pilots experienced in receiver refueling in both the simulator and the aircraft.

Data Collection, Analysis, and Results

The data collected include student background, scores of receiver refueling performance in both the simulator and the aircraft (Initial Qualification Pilots only), and student critiques of simulator visual and handling fidelity (before and after training in the aircraft). The simulator and aircraft instructors were provided a data collection package for each student. Each package contained all required data collection forms and instructions for use of the forms. The following sections describe the data collected, the descriptive and/or statistical procedures used for interpretations, and the results obtained.

Student Background Data

Previous receiver refueling experience as pilot in command (PIC) is a student background variable that could contribute to performance differences among students. (Previous experience was always in a different aircraft than the KC-10.) The Student Background Form is completed by the student during Initial Qualification training and presents questions pertaining to previous receiver refueling experience and the type, amount, and recency of that experience. In order to determine if subjects with previous receiver refueling experience should be considered separately from subjects without previous experience in the analysis of performance data, a non-parametric test, the Kruskal-Way ANOVA by ranks, was used to test for significant differences in the performance scores on the last receiver refueling simulator mission between experienced and non-experienced subjects.

Sufficient data was available only for an analysis of the KC-10 Day (a KC-10 as the tanker under daylight conditions) receiver refueling condition. Five students had previous receiver refueling experience and 11 students had no previous experience. (Previous experience did not include receiver refueling in the KC-10.) At the .05 or .01 levels of significance, the analysis indicated that no significant difference existed between the last simulator performance score for students without previous experience and those with previous receiver refueling experience. Because of this result, further analyses did not separate the data collected based on whether the student had previous experience or not.

Student Performance Data

Measures of student receiver refueling performance were collected during simulator and aircraft receiver refueling missions. The Performance Score is an objective measure based on the rate at which errors are made.

A Performance Score is determined from the elapsed time (in seconds) the receiver pilot is connected to the tanker air refueling boom prior to a disconnect, the type of disconnect (inadvertent or intentional/malfunction), and the conditions (type of tanker, KC-10 or KC-135, and day or night). The data is collected each time the student establishes contact with the tanker during the refueling mission. The Performance Score is computed by dividing the number of inadvertent disconnects by the total contact time. This result is multiplied by 100 to arrive at a more workable number::

Receiver Refueling Performance Score = D/T * 100

Where:
D = Number of inadvertent disconnects
T = Total time on boom in seconds

An inadvertent disconnect is defined as a disconnect caused by the receiver pilot leaving the boom envelope or disconnecting prior to leaving the envelope because of an inability to maintain position. A disconnect caused intentionally by equipment malfunctions is not counted against the student. The Performance Score then is the reciprocal of the average time on boom before an inadvertent disconnect. This represents a score for the rate at which errors are made. Poor performance (high error rate) is indicated by high performance scores; a score of zero indicates perfect performance (no inadvertent disconnects).

The hypothesis investigated is that change in pilot performance of the receiver refueling task from simulator to aircraft is non-existent (or very small) and positive (better performance in the aircraft than in the simulator). The Wilcoxon Matched-Pairs Signed-Ranks test, a non-parametric test for matched samples or repeated measures of the same subject, was used to test this hypothesis.

The analysis of Performance Scores used data from simulator and aircraft receiver refueling missions. Sufficient data was available only for analysis of the of KC-10 Day (eight students) and KC-135 Day (seven students) conditions. The Performance Scores for the last simulator mission and first aircraft mission are listed in Tables 1 and 2 below. The results of the Wilcoxon Signed Ranks tests showed no significant difference at the .05 or .01 levels between performance scores on the last simulator mission and those on the first aircraft mission for either KC-10 Day or KC-135 Day.

TABLE 1 - Last Simulator and First Aircraft Scores for KC-10 Day

STUDENT	SIMULATOR	AIRCRAFT
1	.11	0
2	0	0
3	1.43	.83
4	.67	.60
5	1.10	0
6	0	.07
7	1	.63
8	.48	2.22

TABLE 2 - Last Simulator and First Aircraft Scores for KC-135 Day

STUDENT	SIMULATOR	AIRCRAFT
1	1.82	0
2	0	1.18
3	1.48	.83
4	.72	2.30
5	2.22	.28
6	1.18	0
7	15	.14

Student Critiques of Simulator Receiver Refueling

Three critiques were completed by students at the end of simulator or aircraft training: Pre-flight training, Post-flight training, and Refresher training. The Pre-flight training critique contained questions pertaining only to the visual system, because students had never flown the KC-10 and were not in a position to compare simulator handling characteristics and responsiveness to the aircraft. However, it was felt that the students could comment on the adequacy and usability of the simulator visual. Post-flight training and Refresher training critiques included questions comparing simulator control responsiveness and characteristics to the actual aircraft and visual cues used in actual receiver refueling in the aircraft. In addition, the same questions about the visual system that were asked on the Pre-flight training critiques were included in the Post-Flight Training critique. This allowed the simulator training only receiver refueling critique responses to be compared to those critiques completed by students exposed to both simulator and aircraft receiver refueling. It may be the case that student perceptions *of simulator adequacy change after exposure* to the real world environment of receiver refueling.

Those critique questions answered yes or no were analyzed using Chi Square to determine if there was a significant difference of opinion between those students exposed only to simulator training and those exposed to the simulator and aircraft. The answers supplied in response to the remaining critique questions were reviewed, and the answers and comments summarized and listed below.

The analysis of the KC-10 Simulator Receiver Refueling Critiques focused on those questions requiring yes/no answers in order to determine if there was a difference of opinion regarding the adequacy of the simulator visual system between students exposed only to simulator training and students exposed to both simulator and aircraft training. The frequency of yes and no responses to the question, "Did the visual system provide realistic cues for receiver refueling?" are summarized below.

	Simulator Training Only		Simulator & Aircraft	
	Yes	No	Yes	No
KC-10 Day	13	0	12	0
KC-10 Night	10	3	7	1
KC-135 Day	13	0	12	1
KC-135 Night	7	4	6	2

Since the responses regarding the KC-10 and KC-135 Day conditions obviously indicate a concurrence of opinion, Chi Square was used to determine if the responses for only the KC-10 and KC-135 Night conditions were significantly different. The results indicate that the responses are not significantly different between those students exposed only to simulator receiver refueling and those exposed to simulator and aircraft training.

Two additional yes/no type questions were asked of those students trained in both the simulator and the aircraft. The questions and responses are included below.

1. Was simulator response to control inputs realistic?
   Yes = 8 No = 5

2. Was simulator response to power inputs realistic?
   Yes = 12 No = 1

A Chi Square was computed for the first question and the results indicated that the difference of opinion is not significant.

The simulator receiver refueling training critiques also contained questions pertaining to the visual cues used by the receiver pilot during refueling. Those students trained only in the simulator listed those visual cues used in the simulator; those students who had trained in both the simulator and the aircraft listed those cues used in the aircraft. The questions referred to two phases of receiver refueling: (1) closure from 1/2 mile to the precontact position (50 feet from the boom), and (2) closure to the contact position and maintenance of that position. The responses are summarized below and listed by simulator training only and simulator and aircraft training for comparison purposes. Sufficient data was available only for the KC-10 and KC-135 Day conditions.

1. What visual cues do you use to close from 1/2 mile to precontact position (50 feet from boom)?

KC-10 DAY

Simulator Training Only	Simulator & Aircraft Training
Tanker Boom	Tanker Boom
Tanker position in windscreen	Tanker position in windscreen
UHF antenna	UHF antenna
	Drain mast

KC-135 DAY

Simulator Training Only	Simulator & Aircraft Training
Tanker boom	*Tanker boom*
Tanker position in windscreen	Tanker position in windscreen
UHF antenna on white line	UHF antenna on white line

2. What visual cues do you use to close to the contact position and maintain that position?

KC-10 DAY

Simulator Training Only	Simulator & Aircraft Training
Pilot Director Indicators	Pilot Director Indicators
UHF antenna	UHF antenna
Tanker position in windscreen	Tanker position in windscreen
	Drain mast
	Flap hinges

KC-135 DAY

Simulator Training Only	Simulator & Aircraft Training
"T" on underbelly (inverted)	"T" on underbelly (inverted)
Pilot Director Indicators	Pilot Director Indicators
Tanker position in windscreen	Tanker #4 engine position
UHF antenna	UHF antenna
Tanker engine position	

This summary indicates that there is little difference in the visual cues used for receiver refueling whether the pilot is in the simulator or the aircraft. Pilots in the aircraft seem to be better able to use cues of fine detail, such as flap hinges, which are not usable in the simulator but the most common cues, for example, the boom and the tanker position in the windscreen, can be effectively used in the simulator and the aircraft.

Those students who received training both in the simulator and the aircraft were asked two additional questions regarding the use of visual cues in receiver refueling. These students were asked to list useful aircraft visual cues that were not present, or not useful, in the simulator. The results are summarized below.

KC-10 DAY
- Antenna on gear door
- Detail of wing underside, detail of engine
- Antenna on nose

KC-135 DAY
- Sides of engines, certain panels, detailed engine pylons

With the exception of the antenna, which had been reported as being a useful visual cue in previous questions, students reported those cues that require a degree of detail not possible with the present visual system as being useful in the aircraft but not in the simulator.

The other question asked the students to list any simulator visual cues that they found useful that did not work in the aircraft. There were none reported. This data indicates that the students do not depend on a feature of the simulator visual that is not usable in the aircraft.

DISCUSSION

The Kruskal-Wallis analysis of previous receiver refueling experience and it's effect on final simulator performance indicates that there is no significant difference in the performance of those students with previous receiver refueling experience and those without such experience. Several factors must be taken into account when considering this result. First, the students did not receive the same amount of training in receiver refueling. The training program is designed to be flexible enough to address specific student weaknesses by allowing extra time on those areas. Therefore, if a student did not have any previous experience in receiver refueling, more time would be spent on training for this task than would be spent by a student who had previous experience and demonstrated the basic skills. However, the intent of the analysis was to determine if student receiver refueling performance was equivalent upon completion of simulator training. If there had been a significant difference, the groups would have had to be analyzed separately with respect to performance in the aircraft. Since the difference was not significant, the performance scores for both groups were combined.

The finding that there was no significant difference in Performance Scores between the last simulator mission and the first aircraft mission (for KC-10 and KC-135 Day conditions) supports the hypothesis that training in the simulator transfers to the aircraft. This finding indicates that less aircraft training time is required for a student to become proficient in the receiver refueling task. Reduced training of the receiver refueling task in the aircraft will result in improved safety and reduced costs. Another consideration from this finding regards the development of a trainer dedicated only to the air refueling task. The implication is that it may not be cost effective to include a simulator and a dedicated air refueling trainer in the suite of training devices allocated to a training system. It is less expensive to build a simulator that, in addition to simulating most training tasks, can also address the requirements of training the receiver refueling task than it is to build both a simulator without such a capability and a device dedicated solely to the receiver refueling task. In addition, the simulator has the capability to simulate an entire refueling mission, including rendezvous and Flight Engineer participation. This capability is lacking in a dedicated air refueling trainer.

An analysis of the critique data using Chi Square showed no significant difference in the visual capabilities of the simulator between those students exposed only to the simulator and students exposed to both the simulator and aircraft. This is evidence that the simulator visual system can realistically create a receiver refueling environment. Those students trained in both the simulator and aircraft also had no significant difference of opinion regarding the realism of the control and power inputs in the simulator compared to the aircraft. This indicates that the simulator can also realistically replicate the kinesthetic environment of receiver refueling. Since the conclusion of this study, improvements to the air data package in the simulator have been implemented that make the simulation even more realistic.

An examination of the visual cues used by students in the simulator and the aircraft shows that almost all cues are usable in either environment. Those cues that were not useful in the simulator were of fine detail, difficult for the simulator to realistically display. An upgrade of the visual systems is planned that will add even more realism to the receiver refueling visual environment.

ABOUT THE SPEAKER

Mr. Frederick C. Hartstein is the Director of KC-10 Training for McDonnell Douglas Training Systems, Inc. Bedford, Texas. He is currently responsible for the day to day operation of three KC-10 aircrew training sites. He directs all phases of KC-10 simulator, cockpit procedure trainer, boom operator trainer and academic aircrew training for United States Air Force pilots, flight engineers, boom operators, senior staff, and instructors for each of these crew positions. He holds a BA from Louisiana Tech in Professional Aviation and a BS from the University of New York in Social Science. During twenty-five years in the United States Air force he supervised and managed aircrew flight examiner personnel and personally participated in the development of flight test programs to insure the validity of air refueling data. He flew HH-53 helicopters in Vietnam and participated in the testing of a video/infra red limited night recovery system in simulated and actual combat conditions. Mr. Hartstein retired from the USAF in February 1980 with the rank of Lieutenant Colonel. During 1980 - 1981 he was assistant to Logicon's KC-10 curriculum development program manager. This division developed the complete aircrew training curriculum required to train Air Force KC-10A aircrews. He has extensive experience in training system development including writing functional specifications for training devices, performing systems integration, and developing flight crew training scenarios. Mr. Hartstein has 36 years of diverse military and commercial aircrew training experience. He is a member of the Royal Aeronautical Society and The Order of Daedalians.