SIMULATOR TRAINING AND PLATFORM MOTION IN AIR-TO-SURFACE WEAPON DELIVERY TRAINING

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SUMMARY

The objectives of this research were to determine: (1) the extent to which generalized, conventional, air-to-surface (A/S) weapons delivery training in the Advanced Simulator for Pilot Training (ASPT) transferred to a specific aircraft; (2) the contribution of six degree of freedom platform motion to the transfer of training from simulator to aircraft; and (3) the differential effects, if any, of this simulator training on student pilots of different ability levels. These objectives were accomplished by selecting 24 students in the lead-in A/S training course at Holloman AFB to serve as subjects. These subjects progressed through lead-in training, receiving all training except the A/S flights, and then proceeded to Williams AFB where they were assigned into matched experimental and control groups. At Williams AFB, all of the subjects received academic training in weapons delivery techniques and procedural training on F-5B operations. At this point, the students in the control group flew two data collection sorties in the F-5B aircraft, performing 10^{o}, 15^{o}, and 30^{o}, bomb deliveries. The experimental groups received A/S weapons delivery training in ASPT on 10^{o}, 15^{o}, and 30^{o} bomb deliveries with a fixed number of trials on each event. The experimental subjects then received two data collection flights in the F-5B identical to those received by the control group. Analysis of the results proved that simulator training significantly increased air-to-surface weapons delivery skills (e.g., approximately double the number of qualifying bombs, a one-fourth reduction in circular error) but that platform motion was not a contributing factor in this process. It was also found that novice student pilots of greater initial ability benefit most from such simulator training when a minimum fixed number of trials is used.

BACKGROUND

The air-to-surface mission is a major role for the Tactical Air Command (TAC). A specialized aircraft is being procured to support this operational requirement for which the Air Force plans extensive simulator procurements in order to reduce training costs while maintaining operational readiness. In light of this fact, it is highly desirable to determine the effectiveness of candidate simulator configurations prior to their acquisition by the user. From the user's viewpoint, there are two aspects to this process. First, the simulation must provide the cues essential for training; and second, there must be positive training transfer from the simulator to the aircraft. From a budgetary standpoint, these two requirements are valid, but the cost element must be considered as well. Unnecessary features should not be purchased: the simulation must not only be effective, but also it must be efficient.

One expensive flight simulator feature, of which the universal essentiality is not certain, is platform motion. The question as to whether the existence of simulator platform motion enhances the training effectiveness of the device is an issue of considerable importance. Using a moving platform to provide vestibular and kinesthetic cues to the pilot is a costly process. Not only are initial expenses increased, but life cycle costs are also inflated. Unless some positive training value can be demonstrated for the presence of motion, cost-avoidance consideration must force its exclusion from the simulator.

The Air Force Human Resources Laboratory (AFHRL) recently participated in a study (ASD Project 2235) which facilitated the development of a visual scene capability on the ASPT that included a conventional air-to-surface weapons delivery complex and the display of tactical targets for more advanced operational training. This visual capability, when combined with objective scoring strategies and the existing motion system permitted the investigation of the transfer of training phenomena described in the present study.

Air-to-surface weapons delivery is a high-risk area of training for newly rated pilots. Large Air Force expenditures for simulation of this activity are imminent. Therefore, a determination of both the feasibility of simulator training in this area and an assessment of the contribution of platform motion to simulator effectiveness in this context was deemed essential.

Literature Review. There have been numerous studies investigating the effects of platform motion upon piloting tasks. Many of these have been directed towards determining the degrees of freedom required for motion systems in particular settings as well as what levels of fidelity are needed (Bergeron, 1970; Jacobs, Williges, Roscoe, 1973). This body of research, however, is equivocal, and findings have not always been consistent from study to study.

Certain studies have shown that motion produces improved pilot performance in controlling the simulator (Borlace, 1977, Brown, Johnson and Mungall, 1960). In this vein, Rathert, Creer, and Sadoff (1961) demonstrated that varying the fidelity of motion cueing directly affected the pilot's performance in the simulator. Koonce (1974) investigated the training effectiveness of platform motion using three conditions of motion cueing (i.e., no motion, sustained motion cueing, and washout motion cueing). This study reported an increase in pilot performance in the simulator when either condition of motion cueing was present.

From Koonce's study, it is seen that the evidence supporting the positive effects of high fidelity motion cueing is not firmly established. Demaree, Norman, and Matheny (1965) concluded that in many instances the level of fidelity could be reduced without any appreciable performance decrement on tracking tasks. Huddleston (1966) reported that motion may not be necessary for those piloting tasks performed in the more stable flight regimes, although it may be beneficial in highly dynamic regimes. Finally, a follow-on study to Koonce (Jacobs and Roscoe, 1975) may have revealed a critical facet of the issue. It was found that pilot performance, in terms of errors committed, improved in the simulator with the presence of either normal washout motion or random washout motion where the latter condition provided appropriate onset cueing, but random directional cueing. Perhaps motion serves only to alert the pilot to a change in system conditions and rarely has any intrinsic stimulus value beyond this point (Irish, Grunzke, Gray, and Waters, 1976). Simple "movement," not complexly driven motion platforms, may provide sufficient cues for simulation.

A plethora of studies attest to the training value of simulation (Woodruff and Smith, 1974; Reid and Cyrus, 1974; Caro, 1970; and Prophet, Caro and Hall, 1972). But the effectiveness of simulator training varies enormously when viewed across specific applications, and it is wise to pretest whenever possible. In addition, individual differences in the student population may produce widely different effects of such training. The present study was designed to investigate these possibilities.

Problem Statement. At the present time, TAC air-to-surface training is taught in tactical aircraft. An alternative, if demonstrated to be effective, is the use of flight simulators designed with air-to-surface capabilities. A related issue is the efficiency of this training for student pilots of different ability levels. If the payoff of simulator platform motion does not increase the training transfer to the aircraft, significant reductions in the life cycle costs of the device could be realized.

Objectives. The objectives of this research were to determine: (1) the extent to which generalized, conventional, air-to-surface weapons delivery training in the ASPT transfers to a specific aircraft; (2) the contribution of six degree of freedom platform motion to the transfer of training from simulator to aircraft; and (3) the differential effects, if any, of this simulator training on student pilots of different ability levels.

METHOD AND PROCEDURES

The main theme followed throughout the study was that the approach should be intensely realistic in terms of Air Force operations. This was the determining factor in the study's methodology. Accordingly, it was decided to select a homogeneous group of inexperienced pilots who had already been identified for fighter training, train them on specified tasks in the simulator, then measure their performance on the same tasks in an aircraft on an actual gunnery range. The result was a simple study, easily and quickly understood, that produced information directly applicable to Air Force areas of concern.

Subjects. The personnel who serve as subjects in simulation research are usually found to be the major single source of variance when the analysis of the experimental results is completed. In this study, great care was taken to remove as much of this unwanted variance as possible through the use of judicious selection techniques and counterbalancing.

Subject Background and Selection. It was decided that the most representative source of subjects would be recent Undergraduate Pilot Training (UPT) graduates who had been identified for fighter assignments. These novice pilots receive a short six-week fighter lead-in training course at Holloman Air Force Base, New Mexico, after graduation from UPT and prior to arrival at their Replacement Training Unit. The lead-in course is designed to improve formation flying skills and to provide an introduction to high performance maneuvering and to air-to-ground weapons delivery. At the time of this study, the course contained 19 sorties in the two-place T-38 aircraft, the same aircraft flown in UPT.

The subjects were given the entire lead-in training course with the exception of the air-to-surface indoctrination. This required deleting two T-38 sorties which were replaced by two sorties in the F-5B at Williams Air Force Base as part of the study. The two sorties deleted at Holloman Air Force Base are flown "dry" since the T-38 does not have the capability to deliver ordnance, whereas the two F-5B sorties gave the subjects the opportunity to drop twelve BDU-33 practice bombs which would serve as criterion measures. The subjects were randomly selected from those meeting certain administrative criteria in the training squadron at Holloman. The training squadron then developed a rank ordering of these subjects. This rank ordering was made on the basis of the student's performance during lead-in training.

Subject Assignment. Upon the completion of lead-in training, the student pilots were sent to Williams in groups of six. It was necessary to use four lead-in training classes in order to produce a total N of 24 students, eight subjects assigned to each of three groups.

The rankings given by the squadron at Holloman formed the basis for assigning each subject into either a control group which received no simulator training, or one of two experimental groups (i.e., motion and no-motion groups). For the first class, the subjects ranked 1 and 6 were placed in the motion group, 2 and 5 in the no-motion group, and 3 and 4 in the control group. Class two grouped students 2 and 5 into the motion condition, 3 and 4 into the no-motion condition and 1 and 6 were used as controls. Class three used the last available combination and class four used the first combination over again. Fortunately, this counterbalancing on student performance also produced groups that were well equated from the standpoint of mean fixed-wing flying time. The control group averaged 259 hours, the motion experimental group averaged 276 hours, and the no-motion experimental group averaged 248 hours. These minor differences were not statistically significant at the five percent level of confidence.

It is believed that this procedure accomplished its purposes: namely; subject groups matched as to ability, and a study that would allow valid generalizations on the benefits of air-to-surface simulator training to the appropriate Air Force population.

Instructor Pilots. With one exception, the study's Instructor Pilots were drawn from the 425th Tactical Fighter Training Squadron stationed at Williams. All Instructor Pilots were highly experienced in air-to-surface weapons delivery and were thoroughly briefed on the purposes of the study and their jobs within it. Special training on the ASPT console operation and advanced training features capabilities was given to the Instructor Pilots who administered the simulator training.

Apparatus. The apparatus used in the study consisted of two devices: the Advanced Simulator for Pilot Training (ASPT) and, the F-5B aircraft.

ASPT. The Advanced Simulator for Pilot Training located at the Air Force Human Resources Laboratory/Flying Training Division (AFHRL/FT) was used for the training portion of the study. Technical references for this device are found in Hagin and Smith, 1974; and Rust, 1975, but a short description follows.

ASPT has two fully instrumented T-37 cockpits mounted upon six-degree-of-freedom motion platforms. The synergistic motion system has six active drive legs with approximately five feet of vertical travel and four feet of horizontal travel. Displacement capabilities include: pitch -20 degrees to +30 degrees; roll ±22 degrees; and yaw ±32 degrees. These displacements are intended to provide initial (onset) cues for all maneuvers. The 31-bellow pneumatic G-seat is designed to provide more continuous cues than the motion platform and accomplishes this by the orderly inflation and deflation of the bellows in response to the requirements of each particular maneuver.

The ASPT visual system is comprised of seven 36-inch monochromatic cathode ray tubes placed around the cockpit giving the pilot +110 degrees to -40 degrees vertical cueing and ±150 degrees of horizontal cueing. The computer generated visual scene has the capability to display information for most pertinent ground references (mountains, runways, hangars, etc.) within a 100 square nautical mile area of Williams AFB. The configuration for this study included the conventional gunnery range visual data base developed for Project 2235 and the depressable bombing sight (A-37 Optical Sight Unit) installed for that project (Hutton, et al., 1976).

The aerodynamic math models driving the simulator were those of the T-37 aircraft. The feasibility of changing these models to increase the performance of the simulator to more representative airspeeds and handling qualitites of fighter type aircraft was investigated. Estimates of that effort placed unacceptable time delays on the project which would have not allowed information to be provided to the using command within the required time frame.

A major decision made in establishing the simulator configuration dealt with the G-Seat. The G-Seat can serve as a platform motion surrogate by providing vestibular and kinesthetic cues. If the G-Seat had been included as an independent variable, two additional groups of subjects would have been required for the experiment. This action would have increased the size and duration of the effort by two-thirds. Due to the urgent demand for immediate information on platform motion effects, a larger study was not a viable option. Consequently, it was decided that the G-Seat would be a fixed study factor.

The fully operative motion condition was chosen for the G-Seat configuration. The reason for this selection was that, unlike motion platforms, the inclusion of a G-Seat adds very little to either the acquisition or life cycle costs of a flight simulator. Since it seemed highly probable that all future sophisticated flight simulators would be procured with G-Seats, it was believed that the study results would have greater validity if the G-Seat were operative during the simulator training phase.

F-5B. The aircraft selected for the criterion flights was the F-5B, primarily because F-5B training is accomplished at Williams Air Force Base and the proximity of instructor pilots and aircraft greatly simplified this portion of the data collection. An additional reason for its selection was because it is a two-seat aircraft and two data collection flights per subject could be scheduled with very little checkout time in the aircraft, since an instructor would be on board to perform all tasks not required as part of the study (as well as providing adequate flight safety).

In all, the F-5B proved to be an excellent choice as the criterion test vehicle for measuring the ability of the subjects to perform air-to-surface weapons delivery. The flight characteristics of the F-5B are similar to those of the T-38 aircraft which the subjects had flown for approximately 110 hours in UPT and another 20 hours during lead-in training. Differences in operational procedures and "switchology" were prebriefed prior to each aircraft mission and presented no problems during the data collection flights.

Independent Variables. Four independent variables were used in the study. The first of these, training conditions, represents the weapons delivery training received by the subjects at Williams AFB. There were three levels of this variable: no simulator training (Control Group); simulator training with platform motion (Experimental Group 1); and, simulator training without platform motion (Experimental Group 2). The specific syllabus content and student flow for all three conditions will be covered in a subsequent section.

The second independent variable, coincident with the first, was simulator platform motion. There were two levels of this variable: level one used the full six degree of freedom platform motion available; for level two the platform was stationary.

The third independent variable consisted of the weapons delivery tasks performed by the study subjects. Three different weapons delivery tasks were selected: the high-drag 10 degree dive angle; the high-drag 15 degree dive angle; and, the 30 degree angle dive bomb.

The final independent variable, initial flying ability, was chosen to give greater experimental control and to permit group comparisons on the effects of simulator training as a function of student ability. As stated above, the subjects were rank ordered by the training squadron at Holloman on the flying ability they demonstrated during lead-in training. This served two purposes: first, it allowed counterbalancing of subjects so that there were matched groups in the three training conditions; second, it made possible comparisons on the value of simulator training between students judged to have greater, as contrasted to lesser, initial flying ability.

Study Design. The design used throughout the study was an elementary two-factor "mixed" analysis of variance classified by Lindquist (1953) as a Type I design. The basic design lent itself nicely to the analysis requirements because for two-level contrasts (i.e., motion versus no-motion, superior versus inferior students), it conveniently collapses in simpler paradigms. The three weapons delivery tasks (i.e., 10 degree, 15 degree, and 30 degree dive angles) comprised one factor of this design, while group associated independent variables (i.e., conditions of training, simulator motion configurations, and initial flying ability) constituted the other.

The design was used for the many univariate analyses of variance performed on the data as well as the two multivariate cases.

Dependent Variables. There were two sets of dependent variables used in this study, and both sets had two types of measurements within them.

Aircraft Performance Dependent Variables. Two classes of dependent measures resulted directly from student performance data obtained during the F-5B criterion flights. The first of these, bomb delivery accuracy, were scores from practice bombs dropped on the conventional gunnery range at Gila Bend, Arizona. The second dependent variable based on flying performance was Instructor Pilot ratings. Instructor Pilots flying with the students in the aircraft gave subjective ratings on a scale of zero to four on each bomb delivery attempt which were converted into standard scores (mean of 50, standard deviation of 10) for analytic purposes. These ratings covered overall flying performance in the bombing pattern but excluded any consideration of the actual bomb score.

Simulator Performance Dependent Variables. Similar to the above, there were two classes of dependent measures that resulted from student performance in the ASPT. The first of these, bomb delivery circular error, is a measure comparable in every respect to the corresponding measure observed during the checkrides. A scoring algorithm in the simulator computer captured all release parameters on each delivery and computed an impact distance from the target center.

Capabilities of the ASPT were also used to record simulated flight parameters at the moment of bomb release. Airspeed, altitude, g-load, heading and dive angle were printed out for each weapons delivery. These were the parameters utilized in the multivariate analyses of variance.

Syllabus Development. The first step in the syllabus development was to determine the tasks to be flown. Consideration of F-5B and ASPT capabilities and project objectives resulted in the selection of two low-angle bombing events and one high-angle event. The two low-angle events were 10 and 15 degree simulated high-drag deliveries. The high-angle event selected was the 30 degree dive bomb. The skills required for this event are somewhat different than for the low-angle deliveries because more reliance on in-cockpit instruments is necessary to meet required release parameters.

A prototype syllabus was established and several experienced pilots with no previous air-to-surface training were selected to conduct a pretest of the mission scenarios. These trial runs provided insight into the amount of time required to conduct the training, the optimum length of each sortie, and at the same time provided experience in console operations for the instructors who would be doing the actual training. After several minor changes were made to the syllabus, the course of instruction was administered to a new UPT graduate with flying experience similar to the actual subjects. No problems were encountered and the sequence and instructional techniques were finalized prior to arrival of the first class of subjects.

Subject Training. After their arrival at Williams AFB, all of the subjects were given two blocks of "ground school" training. The first block was presented on the first morning and consisted of an introductory briefing, an overview of the study, and a short phase review of air-to-surface weapons delivery.

At this point, the control group was separated from the experimental groups and given their second block of training, an orientation to the F-5B. This block of training consisted of instruction on aircraft procedures and ended with a test on critical action emergency procedures which were required knowledge prior to flight. For these subjects, the remainder of the first day was spent on the flight line with time in the cockpit to familiarize them with armament procedures and switchology. These control subjects then flew their two data flights in the F-5B on the second and third days (one flight per day). The content of the flights will be described in the section on Testing Procedures.

After receiving the first block of ground school with the control group, the experimental groups then proceeded with their simulator training. They did not receive the second block on F-5B procedures until after the simulator training had been completed.

The syllabus for this training was divided into eight, one-hour sorties. A building block approach was followed throughout. On the first simulator mission, a short familiarization flight was provided prior to starting the actual weapons delivery training. During this time, the subjects experienced the control forces and trim changes that would occur over the airspeed ranges that were later flown. Characteristics of the simulator visual system were explained so the subjects were well-adapted to the outside cockpit environment.

After the familiarization period, the simulator was initialized to the gunnery range for the start of the air-to-surface training. The events were taught in sequence starting with the 10 degree dive angle task. The delivery was introduced with a prerecorded demonstration of the base leg and final approach portions of the pattern. The student was then reset to the same starting point and allowed to practice what he had seen. This part-task approach was selected to take advantage of the available advanced training features such as problem freeze, initialization/reset, and record/playback. After several trials, the student again viewed the prerecorded demonstration. This presentation was dynamic for all flight instruments, stick, rudder, and throttles as well as the visual scene. The Student then flew the part-task pattern again with his own performance recorded. When this was replayed, he had instant feedback which he could use to analyze his own errors. The Instructor Pilots used the problem feature frequently to stop the sequence and to point out what the student should have been seeing and doing. Finally, the full pattern was demonstrated and taught in much the same manner as the part-task pattern.

The second and third missions introduced the 15 and 30 degree tasks using the same procedures. Reinforcement of previously learned patterns was accomplished at several points in the missions. The Instructor Pilots used mission guides in order to follow the sequence exactly on each sortie. Thus, each student in the experimental groups received the same number of repetitions on each of the three bomb delivery tasks.

Testing Procedures. Criterion performance tests were administered in the F-5B aircraft for all groups and in the ASPT for the two experimental groups.

F-5B Tests. Each subject flew flights in the F-5B. The test profile was identical for both flights and consisted of a total of nine bombing patterns on each flight. The F-5B carries six practice bombs, so with three tasks, this resulted in the delivery of two bombs per task per sortie. One extra pattern was flown on each task so a practice run could be accomplished prior to the two actual weapons deliveries.

Simulator Tests. The last two sorties in the simulator were designed to give the subject the same profiles on the simulated range that he would fly on his two aircraft sorties. Each delivery was graded using the same weapons delivery criterion measure used on the aircraft data flights and instruction was minimal. For the scored portions of these flights, the winds were set to represent conditions typical of the Gila Bend Range.

Scoring Procedures. Although the same general approach was used, real-world occurrences naturally beyond experimental control made it necessary to use slightly different scoring procedures for the aircraft criterion missions.

F-5B Tests. Ordnance dropped on the Gila Bend Gunnery Range was scored by observers positioned in towers near the bombing target. Upon impact, a small powder charge in each practice bomb discharged a puff of white smoke which was easily visible. Observers in the two towers used sighting transits to triangulate the location of the bomb impact. The triangulation readings were used to compute the distance of the impact from the center of the target. These circular error scores were relayed via radio to the aircraft after each event. Maximum distance for determining circular error was 300 feet, with anything outside this limit being reported as unscorable. These bombs were arbitrarily assigned a score of 301 feet for purposes of analysis.

Occasionally a malfunction prevented a bomb from releasing from the aircraft. These "no release" passes were rated by the Instructor Pilots since the pattern was flown but simply no bomb score was recorded. This was reflected in the analysis with some subjects having fewer total opportunities which were adjusted for mathematically. Of the total of eight malfunctions that occurred, there were seven in the Control Group, and one in the Motion Experimental Group.

Simulator Tests. The simulator had a theoretically unlimited number of bombs. Each time the pilot released a simulated bomb, the instructor received a graphical display of the bomb impact on a cathode-ray tube which depicted the target circle. He also received a printout of the exact parameters so he could analyze and critique the subjects' performance. Since the computer was scoring the bombs, there were none recorded "unscorable." No release malfunctions occurred during the simulator training.

RESULTS

The research performed in this study addressed three objectives which may be simplified into the following questions:

1. Does simulator training improve air-to-surface weapons delivery skills in novice pilots?

2. Does simulator platform motion contribute to any degree to such training?

3. Does a fixed amount of simulator training affect novice pilots of higher versus lower ability levels to the same extent?

The hypotheses tested in the analyses of results were taken directly from these questions. Accordingly, this section is organized to answer these questions in the order in which they appear.

Simulator Training Effects. The analysis of the ASPT training effects was based on a series of contrasts between the Control Group (C) and the Experimental Groups (E_1 and E_2). The data collected made possible four comparisons. The dependent variables used for these comparisons were: number of gunnery range qualifying bombs; number of gunnery range scorable bombs; gunnery range bomb circular error; and, Instructor Pilot ratings on F-5B flying performance.

Number of Qualifying Bombs. A Chi-Square was performed to test for significant differences in the number of qualifying bomb deliveries made by the C and E groups. Using TAC criteria, qualification was defined as a circular error of 105 feet, or less, for 10 degree and 15 degree dive angles and 140 feet, or less, for the 30 degree dive angle. Both E groups were found to be significantly better than the C group at the five percent level of confidence (χ^2 =6.99). Table 1 lists the observed values and percentages for the three groups.

TABLE 1.

NUMBER OF QUALIFYING BOMBS
(Training Effects Analysis)

	Qualifying Number	Qualifying Percentage	Misses Number	Misses Percentage
C	24	27%	65	73%
E_1	41	43%	54	57%
E_2	42	44%	54	56%

Number of Scorable Bombs. Similar to the first analysis, Chi-Square was used to test for significant differences in the number of scorable (circular error of 300 feet, or less) bombs delivered by the C and E groups. Again, the E groups were significantly better at the five percent level of confidence (χ^2=7.82). Table 2 lists the observed values and percentages for the three groups.

TABLE 2.

NUMBER OF SCORABLE BOMBS
(Training Effects Analysis)

	Scorable Number	Scorable Percentage	Misses Number	Misses Percentage
C	64	72%	25	28%
E_1	82	86%	13	14%
E_2	82	85%	14	15%

Bomb Circular Error. Using the circular error on bomb delivery tasks in the F-5B aircraft as the dependent variable, a Lindquist Type I analysis of variance was conducted to compare the C and E groups on this measure. The overall F value was significant at the five percent level of confidence (F=4.39) and a Tukey Multiple Comparison Test proved both E groups to be superior to the C group at the same level of confidence. There were no significant differences between the E_1 and E_2 groups. Table 3 lists the observed means for each group on the three bomb delivery tasks.

TABLE 3.

BOMB DELIVERY CIRCULAR ERROR MEANS
(Training Effects Analysis)

	10^o dive angle	15^o dive angle	30^o dive angle
C	200'	180'	204'
E_1	148'	138'	169'
E_2	138'	144'	159'

Flying Performance Ratings. The same Lindquist Type I design was employed to analyze differences between the C and E groups where the dependent measure was Instructor Pilot rating of F-5B flying performance. Although the E groups ratings were superior to those assigned the C group at the 20 percent level of confidence, the F value was not significant at the five percent level (F=2.36). Table 4 lists the mean ratings received by each group on the three bomb delivery tasks.

TABLE 4.

FLYING PERFORMANCE RATING MEANS
(Training Effects Analysis)

	10^o dive angle	15^o dive angle	30^o dive angle
C	44.6	48.9	49.4
E_1	52.7	52.7	48.3
E_2	49.4	52.2	51.1

Platform Motion Effects. Considerable effort was expended on the analyses of possible simulator platform motion effects. The results of all this may be summarized at the outset by stating that none were found. However, since the issue is an important one for device configuration, the lack of significant differences and the extreme closeness of the two experimental groups on the dependent measures were of interest.

In addition to the dependent variables previously used for C and E groups contrasts, the simulator data were also available for analysis. The approach taken followed this pattern, analyzing F-5B data first and simulator data second.

F-5B Data: Number of Qualifying Bombs. A Chi-Square Test performed on the data given in Table 1 found no significant differences between the E_1 and E_2 groups (χ^2=.01). In fact, when the hung bomb on one task is considered, the scores of the two groups are identical.

F-5B Data: Number of Scorable Bombs. A Chi-Square Test performed on the data given in Table 2 also showed no differences between the E_1 and E_2 groups (χ^2=.03). Again, allowing for the hung bomb in the E_1 group, the numbers are identical.

F-5B Data: Bomb Circular Error. The Lindquist Type I analysis of variance resulted in no significant differences (F=.06) between the means of the two experimental groups (see Table 3).

F-5B Data: Instructor Pilot Ratings of Flying Performance. As before, the analysis of variance produced no significant differences (F=.03) between the means of the E_1 and E_2 groups (see Table 4).

The analysis of the simulator training data for the motion and no-motion experimental groups also failed to yield significant differences. Four analyses were run on this data. The first analysis used bomb delivery circular error as the dependent variable and was performed to determine if there was an initial difference between the two groups. The second analysis used the same dependent variable and was conducted to see if the groups differed at the conclusion of their simulator training. The third and fourth analyses paralleled these initial and final comparisons but used aircraft delivery parameters (airspeed, heading, release altitude, G-load, and dive angle) as the dependent variables in a multivariate analysis of variance.

Initial Circular Error. A Lindquist Type I analysis of variance was performed on the observed average bomb delivery circular error recorded for each subject on his initial six attempts on each task (i.e., 10, 15, and 30 degree dive angle). The results showed no significant difference at the five percent level of confidence (F=.61). Table 5 lists the observed means for each group on the three bomb delivery tasks.

TABLE 5.

INITIAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Motion Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
E_1	189'	175'	151'
E_2	151'	126'	159'

Final Circular Error. The same procedure was used to determine if the E_1 and E_2 groups final performance (eighth simulator mission) on these tasks differed significantly. At the five percent level of confidence,this was found not to be the case (F=.00). Table 6 lists the observed means for each group on the three bomb delivery tasks.

TABLE 6.

FINAL BOMB DELIVERY CIRCULAR ERROR MEANS
(Motion Effects Analysis)

	10^0 dive angle	15^0 dive angle	30^0 dive angle
E_1	107'	104'	129'
E_2	121'	86''	133'

Initial Attempts Aircraft Delivery Parameters. The basic "groups by tasks" design was employed for the multivariate analysis of variance performed on aircraft delivery parameters observed for the initial three simulator missions. Unlike the univariate cases, there were five dependent variables analyzed simultaneously. Rao's approximation of the F-distribution provided the test of significant (Tatsuoka, 1971). The result was an R-value of .28 which is not significant at the five percent level of confidence. The observed mean differences from the ideal value for each aircraft parameter are given in Table 7 for each experimental group and task.

Final Attempts Aircraft Delivery Parameters. The analysis of the aircraft delivery parameters observed on the eighth simulator mission was identical to that used above. As before, the test for significant differences was Rao's approximation of the F-distribution, and the result was an R-value of 1.63. This was not significant at the five percent level of confidence. The observed mean differences from the ideal value for each aircraft parameter are listed in Table 8 for each experimental group and task.

Subject Ability Levels and Simulator Training. It seemed reasonable to hypothesize that training in the ASPT would improve air-to-surface weapons delivery skills, but an interesting corollary question is: who profits most? Is such simulator training more advantageous for the novice pilot of superior ability or for the novice pilot of inferior ability? Six analyses were performed to answer this question. The first two of these analyses were based on data collected in the simulator; the second four used data collected during the aircraft sorties.

Simulator Data. Using the Lindquist I design, two univariate analyses of variance were conducted to determine whether ASPT training was more beneficial to the subjects rated as the upper one-half or the lower one-half of the class from lead-in training. For these analyses, bomb circular error served as the dependent variable.

The first analysis investigated the initial disparity in weapons delivery skills between the upper one-half and lower one-half groups. It was rather surprising to find that the groups did not differ significantly at the five percent level of confidence (F=.58). Table 9 gives the observed means for each group on the three bomb delivery tasks studied.

TABLE 7.

INITIAL AIRCRAFT DELIVERY PARAMETERS (Motion Effects Analysis)

	10° dive angle		15° dive angle		30° dive angle	
E_1	Heading	1.57°	Heading	2.51°	Heading	4.65°
	Altitude	85.04'	Altitude	55.10'	Altitude	152.09'
	Airspeed	5.63 kts	Airspeed	5.95 kts	Airspeed	6.06 kts
	G-load	.18g	G-load	.22g	G-load	.31g
	Dive Angle	1.39°	Dive Angle	1.05°	Dive Angle	1.46°
E_2	Heading	1.50°	Heading	1.66°	Heading	3.20°
	Altitude	110.01'	Altitude	67.08'	Altitude	111.50'
	Airspeed	4.51 kts	Airspeed	7.55 kts	Airspeed	5.11 kts
	G-load	.14g	G-load	.18g	G-load	.33g
	Dive Angle	1.63°	Dive Angle	$.83^{\circ}$	Dive Angle	1.12°

TABLE 8.

FINAL AIRCRAFT DELIVERY PARAMETERS (Motion Effects Analysis)

	10° dive angle		15° dive angle		30° dive angle	
E_1	Heading	1.39°	Heading	1.85°	Heading	3.21°
	Altitude	82.61'	Altitude	98.71'	Altitude	117.57'
	Airspeed	3.37 kts	Airspeed	4.24 kts	Airspeed	7.16 kts
	G-load	.19g	G-load	.19g	G-load	.25g
	Dive Angle	2.02°	Dive Angle	$.97^{\circ}$	Dive Angle	1.05°
E_2	Heading	1.18°	Heading	1.40°	Heading	4.44°
	Altitude	95.99'	Altitude	73.11'	Altitude	216.48'
	Airspeed	3.73 kts	Airspeed	8.00 kts	Airspeed	4.42 kts
	G-load	.07g	G-load	.15g	G-load	.26g
	Dive Angle	2.64°	Dive Angle	1.09°	Dive Angle	1.63°

TABLE 9.

INITIAL BOMB DELIVERY CIRCULAR ERROR MEANS (Student Ability Analysis)

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	178'	114'	152'
Lower 1/2	174'	185'	158'

At the conclusion of the simulator training, however, there was a definite difference in degree of skill shown by the two groups. The F-value equaled 3.14 and was significant at the five percent level of confidence with a directional hypothesis. Table 10 gives the observed means for each group on the bomb delivery tasks.

TABLE 10.

FINAL BOMB DELIVERY CIRCULAR ERROR MEANS (Student Ability Analysis)

	10° dive angle	15° dive angle	30° dive angle
Upper 1/2	86'	96'	110'
Lower 1/2	132'	94'	153'

Aircraft Data. Four analyses were run using the data from the F-5B sorties as the dependent variables. The first analysis was a Chi-Square test on the number of qualifying bombs delivered by the two groups. The resulting Chi-Square value of 1.57 was not significant at the five percent level of confidence (Table 11).

TABLE 11.

NUMBER OF QUALIFYING BOMBS
(Student Ability Analysis)

	Qualifying		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	46	48%	50	52%
Lower 1/2	37	39%	58	61%

The second analysis was essentially a repeat of the first, except that number of scorable bombs was used as the dependent variable. Again, the Chi-Square test was not significant at the five percent level of confidence (χ^2=1.16). Table 12 gives the observed values and percentages for the two groups.

TABLE 12.

NUMBER OF SCORABLE BOMBS
(Student Ability Analysis)

	Scorable		Misses	
	Number	Percentage	Number	Percentage
Upper 1/2	85	88%	11	12%
Lower 1/2	79	83%	16	17%

When bomb circular error was used as the dependent variable, the Lindquist Type I analysis of variance resulted in an F-value of .73 which was not significant at the five percent level of confidence. Table 13 gives the means for each group on the three bomb delivery tasks.

TABLE 13.

BOMB DELIVERY CIRCULAR ERROR MEANS
(Student Ability Analysis)

	10^{0} dive angle	15^{0} dive angle	30^{0} dive angle
Upper 1/2	119'	162'	143'
Lower 1/2	154'	133'	184'

The same design was used to evaluate Instructor Pilot ratings of F-5B flying performance for the two groups. The resulting F-value of 1.22 was not significant at the five percent level of confidence. Table 14 lists the mean ratings received by each group on the three bomb delivery tasks.

TABLE 14.

FLYING PERFORMANCE RATING MEANS
(Student Ability Analysis)

	10^{0} dive angle	15^{0} dive angle	30^{0} dive angle
Upper 1/2	52.7	51.1	52.7
Lower 1/2	49.4	53.8	46.7

The end result of these four analyses was that although none individually reached the five percent level of confidence, when viewed collectively, they offered strong evidence that it was the superior students who gained most from the simulator training. The outcomes of all four analyses were in the same direction. When the actual probability levels of the Chi-Square and F-test were taken into consideration, the level of confidence reached was beyond the five percent figure.

CONCLUSIONS

Because the study was so basic; its methodology so in conformance with typical Air Force training operations; and, the results so clearcut; there is little to be added to that already presented. Therefore, this section will consist of only a few brief statements summarizing simulator platform motion, and student ability as a variable in simulator training.

Simulator Training. The answer to the question, "Does generalized air-to-surface simulator weapons delivery training transfer to a specific aircraft?" is an unqualified yes. Perhaps the most important aspect of this result, in terms of its implications for simulator and training program design, is the fact that the ASPT was configured as a T-37 (with a sighting device) and still there was significant transfer of training to the F-5B. Although the finding that a low fidelity device can provide considerable training when properly employed is not new (Prophet and Boyd, 1970), the study was a rather striking confirmation of the point.

Platform Motion. It is impossible to prove the null hypothesis, but the results of the study show unequivocally that six degree of freedom platform motion did not enhance the training value of the simulator.

Considering the aerial weapons delivery task, this is not a surprising finding. The task is primarily visual, and motion (or movement) serves only as an alerting stimulus to the pilot.

This fact has significant ramifications for simulator design. The deletion of platform motion requirements for air-to-surface simulation would have enormous cost-avoidance consequences. It is believed that a G-seat and G-suit (with appropriate stick and pedal "shakers") would provide all necessary "motion" cues needed for this simulation.

Student Ability. In this study, it was the better novice pilot who profited the most from the ASPT training. The fact that the better student usually profits more when given minimal fixed amounts of practice and receives the greatest benefits from innovations in training and education is a fairly common observation. The same general finding also occurs even when the content of training program syllabus remains constant, but new media are introduced to convey this subject matter. That the present study was no exception to this general rule adds face validity to the results obtained.

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