# SIMULATION AND TRAINING FOR AIRCRAFT CARRIER LANDINGS

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## ABSTRACT

The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center was used to study the effects of six factors on carrier-landing training. An in-simulator transfer design was chosen, in which students were trained under various conditions, and then tested under a standard condition that represented maximum realism. The experimental design permitted a relatively large number of variables to be studied, using a relatively small number of student subjects. The subjects were pilots who had no prior carrier-landing experience: 16 recent graduates of Air Force T-38 training, and 16 highly experienced Navy P-3 pilots. Factors investigated were field-of-view, scene detail, platform motion, descent-rate cuing and training task (straight-in approaches vs. circling approaches). Turbulence was included as a factor and pilot type (Navy P-3 vs. Air Force T-38) was also included as a factor to control this source of subject variability. After training under a certain factor-level combination, students were tested on the day, wide field-of-view, circling task with motion and without descent-rate cuing. Results showed that the simulator and training factors generally produced either small differences or no differences at all in transfer effectiveness. There were some advantages of the wide field-of-view and high-detail conditions, but these effects were small and/or short-lived, generally disappearing after a few transfer trials. Training with straight-in approaches resulted in transfer performance that was equal to or better than that produced by training with circling approaches. There were no motion or descent-rate cuing effects on the transfer task.

## INTRODUCTION

The Visual Technology Research Simulator (VTRS) at the Naval Training Equipment Center (NTEC), Orlando, Florida is designed for research on flight simulator requirements for training and skill maintenance. The VTRS consists of a fully instrumented Navy T-2C jet trainer cockpit, a six-degree-of-freedom synergistic motion platform and a wide angle visual system that can project computer-generated images onto a spherical screen. The visual system is capable of displaying images via target and background projectors subtending 50 degrees above and 30 degrees below the pilot's eye level and can display 160 degrees of horizontal field.[4]

A major effort at VTRS has involved research to define simulator requirements for the carrier-landing task. There is a need to investigate a large number of visual and other simulator features having substantial cost implications. A research program was planned around the holistic experimental philosophy and paradigm proposed by Simon [11,12] which stresses the importance of studying as many factors of interest as possible within a single experiment. The first phase of this program consisted of performance studies in which the effect of various simulator components on experienced pilots in the simulator was examined.[16,17] The second phase consisted of a quasi-transfer study in which the simulator was both the training and the criterion device. Phase three will eventually include a simulator-to-field transfer study involving actual flight tests. This report presents results from the phase two in-simulator transfer-of-training experiment.

The information obtained from phase one experiments was directly relevant to the design of simulators for experienced pilot skill maintenance and transition training. The information from the phase two experiment reported here is relevant to the design of simulators for undergraduate pilot training. The experiment involved pilots with no carrier-landing experience who trained in the simulator under various conditions representing levels of several simulator equipment and training factors. The pilots were then tested in the simulator in its high fidelity configuration. An in-simulator transfer-of-training paradigm was used to study the effects of six factors plus a pilot-type factor on carrier-landing training. A total of 32 pilots with no prior carrier-landing experience were involved in the experiment. Sixteen were recent graduates of Air Force T-38 training and 16 were experienced Navy P-3 pilots.

## METHOD

### Task

The mission was a daytime carrier approach and landing on the deck of the aircraft carrier Forrestal. The carrier was moving at 20 knots with a zero effective crosswind over the landing deck and 25 knots relative wind down the deck. The mission for this experiment was restricted to include only the final turn of the full circling maneuver as well as the final approach and landing.

### Factors and Levels

A large number of factors potentially affecting the carrier-landing cues were tentatively selected as candidates for study. These were pared down by a panel of engineers and psychologists into a set of factors which were investigated earlier in performance experiments.[16,17] Decisions regarding factors to be included in this in-simulator transfer-of-training experiment were based partly on results from the performance studies. Other considerations were the potential cost impact of factors and the potential training effects and interactions involving factors falling in the category of training aid or type.

"High" and "low" factor level settings were chosen in order to bracket the reasonable range of interest. For the equipment factors, the high levels were generally set at the highest attainable while the low levels were chosen to be the most degraded form of the factor likely to be employed operationally. Other factor levels also bracket the range of interest, but do not necessarily conform to "high" and "low" definitions. A summary of the factors involved in this experiment is given in Table 1.

Field-of-View. The field-of-view high level was a 160 degree horizontal by 80 degree vertical wide-angle display.[14] This wide field-of-view is costly and is representative of that currently available for carrier-landing training only on multi-task trainers such as the 2B35 and the F-14 Wide-Angle Visual System (WAVS). The field-of-view low level was a plus or minus 24 degrees horizontal by -27 degrees to 9 degrees vertical narrow-angle display. This narrow field-of-view is representative of the lower cost Night Carrier Landing Trainers (NCLTs) used for F-4, F-14, A-6, A-7, and S-3 transition training.

Scene Detail. The ship detail for the high detail scene was a daytime solid model computer-generated image (CIG) carrier whose surfaces were defined by 985 edges.[6] The daytime scene included a background seascape colored a uniform blue and a well defined horizon. Brightness levels were approximately 2.80, 0.50, and 0.16 foot Lambert (fL) for the ship, sea and sky, respectively. The detail level was representative of that available from typical daytime CIG systems costing several million dollars. The low level of scene detail was an image of a night point-light CIG carrier consisting of 137 lights. It contained all deck outline, runway, centerline and drop lights. The background was dark with no visible horizon. This display is representative of a night CIG system costing less than a million dollars and used on several Navy NCLTs.

Motion. A six-degree-of-freedom 48-inch synergistic motion platform was fully operational for the high level, and was stationary for the low level of this factor.[3] This platform is similar to those on the Navy's 27 T-2C Instrument Trainers (device 2F101) used in Undergrade Pilot Training (UPT) except that VTRS computation rates are higher for reduced cuing time lag. While it is representative of many older platforms on existing trainers, it does not have the low noise and improved response of new platforms. An attempt was made to fine tune the operational platform for optimal responsiveness for the carrier landing task by setting gains at 7.5, 2.0, and 1.2 for lateral, heave, and pitch cuing, respectively. Roll, thrust, and yaw cuing gains remained at 1.0.

Approach Type. Pilots performed their training trials with either straight-in approaches or circling approaches. For the circling approach the aircraft was initialized abeam the LSO platform at 5700 feet from the ship and at 600 feet of altitude in the approach configuration (full flaps, speed brake out, hook and wheels down and 15 units angle-of-attack). Fuel was fixed at 3200 pounds to give a gross aircraft weight of 10,000 pounds. A trial consisted of the final turn, final approach and attempted landing.

The straight-in approach was initialized with the aircraft 11,990 feet behind the ship and 4150 feet to the left of the runway centerline. The initial altitude was 400 feet with the aircraft in the approach configuration. The aircraft was trimmed for straight-and-level flight in both initial approach conditions. The straight-in approach was defined specifically to provide task requirements similar to the circling approach but with the ship in view at all times under the narrow field-of-view condition. Thus the aircraft was set to the left of the runway centerline and headed at 18 degrees to the right of the ship centerline heading. (At 25 degrees of aircraft heading relative to ship centerline heading the ship would go out of the narrow field-of-view.) Pilots were instructed to fly this modified straight-in approach straight-and-level out of the initial condition until approaching the runway centerline, then execute a turn and rollout on the runway centerline.

This factor was included in the experiment because of the hypothesis that the daytime mission can be trained adequately with (modified) straight-in approaches. This hypothesis was supported by results presented in [5] and by preliminary observation. If this hypothesis were true, it could have implications for the field-of-view question since a wide field-of-view is not required to keep the ship visible to the pilot during straight-in approaches.

FLOLS Rate Cuing. The conventional version of the FLOLS display defined one level of this factor. The other level involved the use of vertical bars displayed with the FLOLS which presented glideslope rate of change information to the pilots. This information was presented to the pilots in "command" fashion, that is, the bar height could be interpreted directly in terms of action required to change to the desired vertical velocity. The height of the bars indicated deviation from correct vertical velocity relative to current glideslope displacement and nulled bars indicated correct vertical velocity for any glideslope position. The FLOLS rate cuing factor was included in the experiment on the basis of VTRS work, which indicated a large improvement in glideslope control with rate cuing displays for experienced carrier pilots.[8,9] The latter reference (Experiment II) includes a description of the algorithms used to define the command rate bar operation.

Turbulence. Turbulence was included in the experiment at two levels to allow examination of other factor effects under two difficulty levels. The two levels, no turbulence and the highest amount of turbulence under which operations would continue at sea, represent the range of expected real-world turbulence. The main effect of turbulence was also of some interest in this experiment as a training variable. Turbulence was generated in the form of "winds" acting on the longitudinal, lateral, and vertical aircraft axis. These winds were pseudo-random sine waves which were generated

TABLE 1. SUMMARY OF EXPERIMENTAL FACTORS AND LEVELS

| FACTORS | LEVEL SETTINGS "low" | "high" |
|---|---|---|
| Field-of-view | -27 degrees to 9 degrees vertical, ±24 degrees horizontal | * -30 degrees to 50 degrees vertical, ±80 degrees horizontal |
| Scene Detail | Night: point-light ship | * Day: solid surface ship |
| Motion | Fixed base | * Six-degree-of freedom |
| Approach Type | *Circling approach | Modified straight-in approach |
| FLOLS Rate Cuing | *Conventional FLOLS display | FLOLS display with "command" rate cuing |
| Turbulence[1] | Close to maximum flyable | No turbulence |
| Pilot Type | Air Force T-38 | Navy P-3 |

*Indicates setting for the transfer test configuration

[1]Turbulence was set at half the "low" level setting for the transfer test.

by the summation of pure sine waves of various frequencies and amplitudes. The RMS values of the winds used were 3.00, 1.25, and 3.00 ft/sec for the longitudinal, lateral, and vertical dimensions, respectively. These values produced a fairly large amount of turbulence judged to be near the limits for safe operation. Frequency and amplitude values used are given in [7].

Pilot Type. Pilots for this experiment were selected from two populations without carrier-landing experience. One group was made up of recent graduates of Air Force T-38 training and the other group was comprised of experienced Navy P-3 pilots. The pilot group factor was included explicitly in the experiment so that the expected large source of subject variance resulting from differences between the groups could be directly estimated and partialled out of the results.

Factors Held Constant. A number of factors investigated earlier were held constant in this training experiment.[16,17] CIG images of both ship and FLOLS were used throughout the experiment. The TV line rate was 1025 and engine computations were done at 30 Hz. Visual lag was at the system's optimum 100 msec and the G-seat was off.

## Transfer Configuration

After completing their training sessions all pilots transferred to an in-simulator maximum realism version of the daytime circling carrier-landing task. The initial position for the circling approach was the same as that used for circling approaches during training. A wide field-of-view was present along with the daytime scene, motion on, conventional FLOLS and an intermediate level of turbulence. RMS values for the "winds" used during training were halved for the transfer test. This amount of turbulence was judged to be somewhere between small and moderate in size.

## Pilots

Pilots for this experiment were volunteers from two populations with no carrier-landing experience. One group of 16 pilots was made up of recent graduates of Air Force T-38 training. All the pilots in this group had approximately 200 hours of total flight time with about 100 hours of flight time in the T-38 in the six months prior to the experiment. The other group was comprised of 16 experienced Navy P-3 pilots. This group averaged 1550 hours of total flight time but varied considerably in overall experience with a standard deviation of 529 and a range of 600 to 2530 flight hours. Experience in the six months preceding the experiment averaged 229 hours, all in the P-3.

## Performance Measures

All of the summary measures described and collected in [17] were also collected for the present experiment. Due to space limitations, analyses for only one measure, which essentially summarizes final approach glideslope performance, are presented here. A percent time-within-tolerance measure for the final approach was used to summarize final approach glideslope performance. This score, referred to as the glideslope tracking score, was calculated from 3000 feet to the ramp and used a tolerance band of ±.3 degree. This tolerance was recommended by Navy Landing Signal Officers (LSOs) and represents approximately plus or minus one "meatball" of deviation of the FLOLS display. Results for other scores are discussed, including a wire (longitudinal) accuracy metric for assessing touchdown quality. This score is similar to Brictson's Landing Performance Score (LPS), but it is based on absolute deviation from the desired touchdown point rather than wire catch *per se*.[2] Touchdowns resulting in a three-wire catch were assigned a score of 100, while touchdowns more than 100 feet behind the one-wire or beyond the four-wire were assigned scores of zero. Touchdowns inside these limits were assigned scores linearly between zero and 100.

## Procedures

The experiment consisted of 40 training trials and 16 transfer trials. Before flying any trials, pilots were given approximately one and one-half hours of instruction in carrier-landing procedures in the form of a briefing and an instructional videotape. They then flew two three-minute familiarization flights in the simulator before commencing with the experimental training trials. Instructional feedback was given after each training trial by a VTRS staff member and an "automatic LSO" was used throughout the experiment to give calls during the flights. (A VOTRAX voice generation system was driven by software developed from a modified version of the model described in [1].) Instructional feedback was not given during the transfer test trials.

## Experimental Design

A transfer-of-training paradigm was superimposed on the basic experimental design which was an adaptation of National Bureau of Standards, Plan 4.7.16.[10] Each pilot performed 40 training trials under one of the conditions of the basic design followed by 16 transfer trials in the simulator on the high fidelity transfer configuration. The basic design was one-fourth of a fully crossed $2^7$ design resulting in 32 experimental conditions and 31 estimable effects.

All main effects are confounded only with three-way or higher interactions as are 15 of the 21 two-way interactions. The other six two-way interactions are confounded in strings of two each and the remaining six estimable terms in the basic design represent strings of three-way interactions. As the basic design was repeated across trials, trial effects are also fully estimable. The two-way interactions judged least likely to be important *a priori* were assigned to the strings of confounded two-factor interactions. Implicit in the use of this fractional factorial design is the assumption that three-way and higher-order interactions will generally be negligible. Each of the estimable effects in the basic design is also confounded with the subject effects defined by the groupings involved in a particular comparison.

## RESULTS

Table 2 presents an analysis of variance summary of transfer test trials for the glideslope tracking score. This analysis estimates effects averaged across all 16 transfer trials which are represented by two blocks of eight trial means. Main effects were tested separately as were the field-of-view by approach type and scene detail by approach type interactions which were considered important *a priori*. All other estimable interactions were examined individually, but in the absence of strong evidence for an effect, were included in various omnibus terms. The basic "residual" term for an analysis of variance was created from the sum of the two- and three-way string terms. The sum of two-way interactions not involving pilot type and the sum of two-way interactions involving pilot type were tested against the basic residual term. If these effects were not significant, they were combined with the residual term to form a residual estimate against which all other effects were tested. Thus, for example, the F ratios shown for the single degree-of-freedom effects in Table 2 have a 22 degree-of-freedom denominator whose sums-of-squares is from all the indicated sources.

The entire transfer-of-training design may be thought of as a special case of a repeated measures' design with observations repeated on a trials' factor.[18] In this sense, the residual estimate represents an estimate of subjects within groups error. Trial blocks were tested against a term comprised of all estimable three-way and higher interactions involving blocks which is then an estimate of error within subjects. Two-factor interactions involving blocks were tested omnibus fashion against this same term.

Figure 1 graphically describes the experimental results for the main effects on glideslope tracking performance. The numbers in parentheses in Figure 1 above a block of trials for the effects represent the results of an analysis of variance for that block of trials. The numbers are the ranks of the sizes of the effects (within the 31 estimable effects) of the basic design. Thus, for example, approach type had the largest effect in the first block of training trials, field-of-view ranked fifth, etc. An effect can rank high by chance alone, of course, and such things as stability over time and effect size must also be taken into account when judging the meaningfulness and reliability of an effect. On the other hand, if an effect size does not rank very high, it probably is neither meaningful nor real since it cannot be differentiated from noise.

Table 2 and Figure 1 indicate a large difference between pilot types on the transfer task. This was not unexpected because of the differing flight backgrounds of the groups and there is little interest in this effect *per se* other than to indicate that this large source of subject variance was successfully controlled. The wide field-of-view results in a sustained transfer advantage of about 6.3 percent more time within $\pm .3^{\circ}$ of the desired glideslope. This effect is the fourth largest in both blocks of transfer trials and accounts for 8.4 percent of the experimental variance on the transfer trials. These results are in the same direction as those obtained in [5], although significance for transfer trials was not obtained in that experiment. Although the field-of-view transfer effect appears real here, it should be mentioned that there was no field-of-view transfer effect on touchdown performance. It is felt that a glideslope effect which is not reflected in touchdown performance should be regarded as small. Thus, in an overall sense, the

TABLE 2. ANALYSIS OF VARIANCE FOR GLIDESLOPE TRACKING ON TRANSFER TRIALS

| Source of Variance | LEVELS High | LEVELS Low | df | | Mean Difference[1] | | F |
|---|---|---|---|---|---|---|---|
| Field-of-view | Wide | Nar | 1 | | 6.3 | (8.4)[2] | 6.45* |
| Scene Detail | Day | Night | 1 | | 4.6 | (4.6) | 3.48 |
| Motion | On | Off | 1 | | 3.2 | (2.2) | 1.65 |
| Approach Type | St. In | Circ | 1 | | 2.5 | (1.4) | 1.05 |
| FLOLS Rate Cue | Cuing | No Cue | 1 | | -3.9 | (3.3) | 2.49 |
| Turbulence | Calm | Winds | 1 | | 2.8 | (1.6) | 1.26 |
| Pilot Type | Nav P-3 | AF T-38 | 1 | | -7.6 | (12.3) | 9.37** |
| FOV X App. Type | | | 1 | | | (-) | 0.49 |
| S. Dtl X App. Type | | | 1 | | | (-) | 0.44 |
| 2-Factor Int (No Pil)[3] | | | 7 | Re- | | (9.7) | 1.14 |
| 2-Factor Int (Pil)[4] | | | 6 | sid- | | (8.1) | 1.10 |
| 2 + 3 Way Strings | | | 9 | ual | | (11.0) | |
| Blocks (8 Trials) | | | 1 | | 5.9 | (7.5) | 8.42** |
| 2-Factor Int (Blocks) | | | 7 | | | (7.4) | 1.18 |
| 3-Factor Int (Blocks) | | | 24 | | | (21.4) | |
| Grand Mean | | | | | 34.8 | | |
| Std. Err. Difference | | | | | 2.3 | | |
| Std. Deviation | | | | | 6.5 | | |

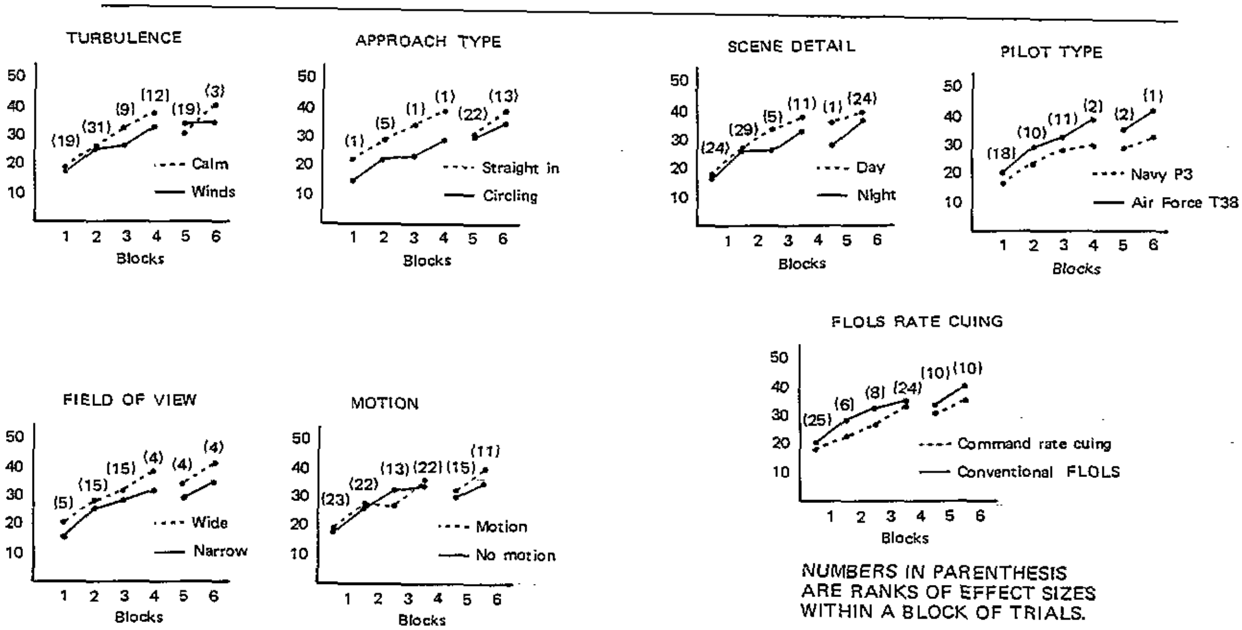
[1]Mean of observations taken under high level, minus mean of observations taken under low level of factor.

[2]Values in parentheses are percent variance accounted for in the experiment. Percents less than 1.0 are shown by a dash (-).

[3]Two-factor interactions not involving pilot type.

[4]Two-factor interactions involving pilot type.

$*p \leq .05$
$**p \leq .01$




NUMBERS IN PARENTHESIS ARE RANKS OF EFFECT SIZES WITHIN A BLOCK OF TRIALS.

BLOCKS 1 - 4 (Training Trials) ARE 10 TRIAL MEANS.

BLOCKS 5 - 6 (Transfer Trials) ARE 8 TRIAL MEANS.

Figure 1. Main Effects for Glideslope Tracking Score: Percent ±.3° of Desired for 3000 Feet to Ramp.

field-of-view impact on transfer performance was not large.

Training on the high level of scene detail results in an initial advantage on the transfer task. As Figure 1 indicates, this is the largest experimental effect on the first block of transfer trials. However, by the second block of transfer trials, this difference has essentially dissipated and the overall transfer effect is not significant, accounting for only 4.6 percent of transfer task variance. No other differential transfer effects were evident, although the approach type effect is noteworthy. Pilots who trained with modified straight-in approaches did as well on the transfer task as those training with circling approaches. This was true despite the fact that the transfer task included a circling approach and those pilots training with straight-in approaches had not flown the circling approach prior to the transfer task. This result is also in agreement with results given in [5].

It should be noted also that the FLOLS command rate cuing did not result in a performance advantage, even during training. This is in contradiction to results given in [8] which show a large improvement in performance with the rate cuing display for experienced pilots. The pilots in this study were completely novice to the task and apparently did not have the skill level necessary to effectively utilize the rate information at this stage, at least not with the command display mode used here. Most pilots did show considerable general improvement in performance over the length of the experiment, indicating that a great deal of learning was taking place over a wide variety of conditions. The Air Force T-38 group, in particular, had reached an intermediate proficiency level by the end of the experiment, an accomplishment which suggests considerable potential for the simulator as a trainer for the carrier-landing task.

## SUMMARY

The following summary of this experiment includes more extensive results presented in [15] as well as the limited results presented here. The main conclusion to be drawn from the results is that equipment differential transfer effects were small from a practical point of view. Transfer landing quality was not affected by any factor other than pilot type and approach quality was generally only temporarily affected by equipment factors, i.e., effects had essentially disappeared after eight transfer trials. The only exception to this is field-of-view which did show a sustained effect on glideslope tracking performance. Although final approach effects are important in their own right, approach effects that are not reflected in touchdown performance must be regarded as small. The pilot type effect was generally larger than all other effects combined and the only other factor that had a sizable, sustained transfer effect was a training factor, approach type.

These findings have important implications for simulator design. They suggest that cost and reliability considerations should play the major role in selecting the design for an undergraduate carrier-landing simulator. Simulator hardware advance has apparently reached a stage--at least for the carrier-landing task--where costly increases in fidelity have smaller effects than pilot and training factors and are producing small gains at best. The findings suggest that optimal cost-effective training will occur with a relatively low-fidelity simulator (as defined by the low levels of factors used in this experiment) and judicious use of training variables and schedules.

### Individual Factors

A brief summary of results follows with the factor effects listed in the order of estimated overall impact on the transfer task.

Pilot Type had by far the largest effect during the transfer trials but the effect was dependent on the dimension of performance measured. Air Force T-38 pilots did better than Navy P-3 pilots on glideslope tracking and landing wire accuracy, but P-3 pilots did much better on final approach lineup tracking and angle-of-attack control.

The straight-in approach type training resulted in better final approach lineup control on the transfer task despite the fact that the transfer task involved a circling approach. Pilots training with straight-in approaches had 15% more time within the lineup tolerance limit on the transfer task than pilots training with circling approaches. Also, the circling approach training showed no transfer advantage for other final approach scores or landing accuracy.

The wide field-of-view resulted in some advantage on the transfer task for final approach quality but not landing accuracy. There was a sustained effect on glideslope tracking and a temporary effect on lineup and angle-of-attack tracking. The overall effect on final approach quality after eight transfer trials was small at best.

Daytime scene detail training conditions showed no transfer advantage over night scene detail training conditions on landing accuracy. There were transient effects on glideslope and angle-of-attack performance with the daytime training scenes showing the advantage. There appeared to be a lineup performance advantage on transfer for the daytime training scenes but only with straight-in training approaches.

The presence or absence of motion during training did not make a difference on transfer. The addition of rate cuing information to the FLOLS did not result in a transfer advantage compared to training with a conventional FLOLS.

### Considerations

Two things should be kept in mind when considering these results. First, as mentioned earlier, subject effects defined by the particular group comparisons were confounded with experimental effects. Although this is true for any transfer-of-training design, the problem is more acute with the one-subject-per-cell design used here in which there was an a priori interest in examining most of the estimable effects. It is very likely that a few experimental effects will be more than trivially biased by subject effects. The subject factor (pilot type) which was included in the experiment did remove a large amount of subject variance and thus reduces this concern somewhat. Further, a covariate task was employed in the experiment (not reported here) which showed some relationship to the criterion task.[15] Taking into account this covariate, resulted in only trivial effect estimate changes for effects of interest. Thus there are grounds for suggesting that subject confounding was adequately controlled, but this problem was not fully resolved.

Second, there is the issue of generalizability of results because of the in-simulator "quasi" transfer of training design. Ultimately, a simulator-to-field study with undergraduate Naval aviators is needed to confirm these results. This study provides recommendations for such an experiment and at the same time depends on a field-transfer study for its own ultimate value. Confirmatory results could go a long way toward increasing confidence in in-simulator results and thus saving some of the enormous expense associated with field-transfer studies.

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