HELICOPTER SHIPBOARD LANDING RESEARCH AT THE VISUAL TECHNOLOGY RESEARCH SIMULATOR

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ABSTRACT

Simulator design and instructional issues for helicopter shipboard landing operations are presently under investigation at the Navy's Visual Technology Research Simulator (VTRS) following the recent installation of a Vertical Take-Off and Landing (VTOL) simulator. Research strategy at VTRS to provide answers for applied training problems has employed economical multifactor experimental design to deal with the many factors which may influence performance and an iterative three phase process to deal with "transfer of training" as the ultimate issue. The first phase of this process consists of performance studies in which the effect of various design features on experienced pilots are examined in the simulator. The second phase consists of in-simulator transfer-of-training experiments in which pilots novice to the task are trained under various simulator configurations and instructional conditions and then tested under a high fidelity simulator configuration. The third phase employs the transfer-of-training experimental paradigm with training in the simulator and testing at an operational site. Currently, the VTRS helicopter shipboard landing research program is in the second phase. This paper presents results from two major performance experiments already completed, and show how the results were used to progress from the first experiment to the second and then to the current in-simulator transfer-of-training experiment, which will also be discussed.

INTRODUCTION

A major focus of the research effort at the Navy's Visual Technology Research Simulator (VTRS) is to experimentally evaluate simulator design options and training procedures for important flight tasks. This research provides guidelines for (1) decision making for flight simulator design options, and (2) the development of instructional procedures to achieve optimal use of simulator training time. Currently, simulator design and instructional feature issues for the helicopter shipboard landing task are under investigation. A program of research is underway which includes performance experiments and transfer-of-training experiments.

RESEARCH STRATEGY

A three-phase research process, combined with principles of economical multifactor experimental design, has been employed to quickly investigate many simulator design and instructional feature issues economically and in a reasonable period of time. The three phase approach has been used previously in VTRS research to determine simulator design requirements for the carrier landing task [10, 7, 12] and for air-to-ground weapons delivery [8, 3, 2]. This research has been partially summarized by Lintern, Wightman and Westra [4]. This process is iterative in nature wherein information obtained at each phase is used in the planning and design of succeeding phases. The first phase of this process consists of performance experiments in which the effects of various design features on experienced pilots are examined in the simulator. The second phase of this process involves in-simulator transfer-of-training experiments which employ the transfer-of-training experimental paradigm. In this phase, pilots novice to the task are trained in the simulator under various simulator configurations and instructional conditions and then tested under a high fidelity simulator configuration. The third phase employs the transfer-of-training experimental paradigm with transfer testing taking place in the field. Currently, the VTRS helicopter shipboard landing research program is in the second phase. This paper will present results from two performance experiments already completed, and show how the results were used to progress from the first experiment to the second and then to the current in-simulator transfer experiment.

Although transfer of training is the bottom line in training research, performance experiments are extremely valuable, indeed necessary, as the first phase of a research program investigating the effect of a large number of factors. First, they serve as a vehicle to develop and validate performance measures and experimental procedures. Second, they serve to "screen" variables for subsequent transfer experiments. Factors that have little or no effect on performance are unlikely to affect transfer and may be excluded from transfer experiments. This assumption may be questioned, but exceptions are difficult to find in the literature. Preselection has always been a part of planning for transfer studies, and in cases where theory and prior data do not offer a useful guide, performance experiments provide a rational basis for factor selection.

Third, the results from performance experiments, particularly in the case of null results, do provide direct information regarding skill maintenance or transition training for experienced pilots. And, finally, by taking advantage of experimental designs which use the same subject across numerous conditions, a great deal of information can be obtained at relatively low cost. This means that even very large-scale multifactor experimental designs can be conducted with only relatively few representative pilots. In contrast, pilots can perform on only one training condition in a transfer-of-training experiment, so that the conduct of even an in-simulator transfer experiment of any reasonable power requires a great deal of resources. Conducting a field transfer-of-training experiment requires even greater resources, introduces difficult logistic problems, and can reduce experimental control. Thus, it would appear not only prudent and economical to employ this research strategy, but necessary in the case of a many factor problem for which generalizable, applied results are desired. In all three phases of research a holistic experimental philosophy is used as proposed by Simon [6].

RESEARCH PROBLEM

Landing a helicopter on a small ship is a particularly difficult task and that difficulty is accentuated in turbulent seas. Typically, the pilot establishes the aircraft on a descent path about one mile behind the ship and approaches the landing area while reducing speed. The pilot transitions to a hover relative to the ship at a height of approximately 15 feet above the landing deck. A hover is maintained above the touchdown point until the pilot ascertains that the deck is level and stable enough for a safe landing. At that moment, the aircraft is quickly lowered to the landing area and secured to the deck. Communications from the fleet indicate that their present simulator is not satisfactory for teaching the final stages of the helicopter approach and landing.

The Light Airborne Multipurpose System Mark III (LAMPS MK III) integrates an FFG7 frigate and a SH-60B Sea Hawk helicopter to provide an over-the-horizon detection and strike capability for antisubmarine warfare and antiship surveillance and targeting. The system has recently been introduced to the U.S. Navy and it is anticipated that approximately 100 units (i.e., 100 ships and 200 aircraft) will eventually be deployed. The SH-60B cockpit was installed at the VTRS facility so that simulator design and instructional issues for helicopter small ship operations could be examined.

VTRS RESEARCH FACILITY

The simulation at the VTRS facility supporting helicopter training research includes an SH-60B cockpit with all displays and controls that are important for flight control and guidance. These displays and controls function in real time and closely simulate those of the aircraft within the flight regime of the approach and landing. The cockpit is mounted on a fixed base in a 17-foot (5.18m) radius dome. It has a pneumatic g-seat, with buttock, thigh, and back cushions that simulate tactile pressures experienced in flight. Twin 1025-line color projectors are used to provide a 160 degree (H) by 70 degree (V) computer generated image of the outside visual scene. This field of view is set 40 degrees to the left, 120 degrees to the right, 20 degrees above, and 50 degrees below the forward line of sight set for helicopter operations. Maximum scene brightness is approximately 0.2 ft Lamberts (0.685 cd/m²). Herndon [1] provides a more complete description of the VTRS helicopter simulator.

PERFORMANCE EXPERIMENT I

Eight experienced Navy pilots made approaches and landings on a representation of an FFG7 frigate in the vertical take off and landing (VTOL) simulator at the VTRS. The pilots were from operational squadrons and routinely flew VTOL aircraft in helo/ship operations. The experimental task involved the approach and landing of the simulated SH-60B helicopter to a simulated FFG7 frigate moving forward at 10 knots (18.5 Km/h). The aircraft was initialized at 160 feet (48.4m) altitude on an approach heading 2000 feet (609.3m) behind the ship. The simulated aircraft was initialized at an airspeed of 43 knots (79.9 Km/h) for a descent rate of 128 feet per minute (39.0 m/min) descending approach to the FFG7. The glideslope approach angle was nominally set at 3.5 degrees, although no glideslope indicator was available and pilots were not specifically concerned with maintaining that approach angle. The approach and landing involved a descending and decelerating approach to the ship, transition to hover near the stern, hover over the landing area, and descent to the designated rapid securing device (RSD). A complete description of this experiment and the results was reported in Westra and Lintern [11].

Factors and Levels

Factor and level settings represented those of most interest and were generally chosen to bracket the reasonable range of interest. "High" factor levels were generally set at the highest fidelity attainable under VTRS capabilities. Low level settings represented the most degraded form of the factor likely to be used in an Operational Flight Trainer (OFT) or a level currently being used in a flight trainer. One exception to this was the scene detail factor whose "low" level was little more than an outline of the ship with solid surfaces. This was done as the first step in a process of identifying and isolating specific scene detail effects.

In all cases, the factor contrasts involved fidelity and cost issues, and in some cases a considerable cost difference was represented. Seastate/turbulence and pilot experience were added to enhance the generalizability of the experiment. Factors and levels are summarized in Table 1. The field-of-view "low" level was set to represent values for the SH-60B OFT (preliminary design values since the OFT was not yet operational), while the "low" setting for visual delay (217 msec) represents the slowest response time normally considered in simulators with visual systems. Both g-seat acceleration and vibration cueing were included in the experiment so that g-seat effects could be fully determined.

Performance Measurement

Raw data were recorded at 30 Hz and reduced to a set of trial summary measures. For measurement purposes, the task was partitioned into four segments. These segments were (1) the approach from 1500 feet astern to the stern of the ship, (2) transition from the stern to a hover above the landing point, (3) hover above

TABLE 1. EXPERIMENTAL FACTORS AND LEVELS

FACTOR	LEVELS "LOW"	"HIGH"
Scene Detail	Outline of deck & hangar	Full Deck & hangar markings, ship's wake and seascape patterns
Field of View	20 deg left to 100 deg right, 15 deg up to 25 deg down (left half field), and 3 deg up to 40 deg down (right half of field)	40 deg left to 120 deg right 20 deg up to 50 deg down
Visual Delay	217 msec	117 msec
G-seat Cueing	Off	Translation and angular accelerations
G-seat Vibration	Off	Oscillating cushions
Collective Sound	Off	Augmented aural cues
Seastate	Moderate seastate and medium air	Calm with no air turbulence
Average Flight Experience	830 hours	2323 hours

TABLE 2. SUMMARY OF EFFECTS

Factor	Effect Size	Segment/Measures	Best Option*
Scene Detail	Moderate/Large	All segments/most quality measures, pilot opinion	High detail
Visual Delay	Small/Moderate	Hover, touchdown roll, pitch control, pilot opinion	117 msec
Field of View	Small	Approach, hover touchdown/lineup control, aircraft pitch	Wide FOV
G-seat Vibration	Small	Approach, hover descent/stick lateral cyclic	?
G-seat Acceleration	None		?
Collective Sound	None		?

* The option that resulted in best simulator performance. In cases where quality measures were not affected, no determination of "best" performance was possible.

the landing point, and (4) descent to touchdown. Primary summary measures were root mean square (RMS) error from the prescribed flight path and touchdown error scores. Extensive pilot opinion data were also collected via questionnaires. More detail on performance measurement can be found in Westra and Lintern [11].

RESULTS I

Scene detail had by far the largest effect with most measures and all task segments affected. Performance was considerably better with the high detail ship and wake scene. Visual delay had the next largest effect of the equipment factors. There was a small but significant effect in favor of the shorter delay time. Pilot opinion strongly supported this effect. Field of view was ranked next in terms of overall effect magnitude with mostly small performance effects favoring the wide field of view. G-seat acceleration cueing, g-seat vibration cueing and collective sound had essentially no meaningful performance effects in the experiment. The effects are summarized in Table 2. Effect size refers to the degree of variability in performance which can be attributed to the factor listed.

DISCUSSION/RECOMMENDATIONS I

Ideally, if no particular problems with methods, measures, equipment and procedures were noted, the results of a performance experiment would feed directly into the planning and design for an in-simulator transfer experiment. Unfortunately, several problems came to light which suggested that further work was needed before moving to the in-simulator transfer experimental stage. First, despite extensive development work and pretesting, the g-seat acceleration cueing was judged by most pilots to be inaccurate and distracting. Also, performance differences were not noted with the g-seat cueing present. Therefore, more work was required to determine if g-seat cueing could affect performance.

Second, with the task performed continuously from start to touchdown, there were problems with widely varying amounts of time spent in the hover. Two pilots in particular typically came over the stern low and quickly landed, often resulting in little or no hover time during which data could be collected. Since the hover is considered a very important element of the task, this problem was considered serious enough to warrant a change in procedures so that hover data would be collected. Third, performance measurement was considered inadequate for fully documenting the visual delay and g-seat effects.

The scene detail effect indicated that the low detail scene tested was inadequate and it was recommended that this level not be studied further. It was also concluded that the longer visual delay was unacceptable for this task. Since performance effects were small, it was felt that the relatively narrow OFT field of view was adequate. However, it was noted that representation of the chin window area is important, and this area was not fully tested in the experiment. G-seat vibration and collective sound had no appreciable effects on performance but pilots seemed to like these features as indicated on the pilot opinion surveys. It was recommended that they be incorporated into the simulation and not studied further, since they are relatively inexpensive, add face validity to the simulation, and do not impair performance.

PERFORMANCE EXPERIMENT II

Based on the outcome of the first performance experiment, a second performance experiment for the helicopter shipboard landing task was planned and conducted. This research effort actually consisted of two separate experiments; an approach, hover, and landing task, and a precision hover task. The precision hover task was selected both to correct procedural problems by insuring a defined hover segment, and to enhance performance measurement. The hover task was set up to include wind gusts at specific times so that pilot reaction time and frequency response under different conditions could be measured. Other measures of aircraft control and activity were also added to the performance measure set to insure complete description of any effects. A complete description of this research effort and results is given in Westra, Sheppard, Jones, and Hettinger [9].

A number of developmental improvements were made to the g-seat cueing algorithms in an attempt to correct the deficiencies noted in the first experiment. In particular, the acceleration cueing drive algorithms were deemphasized with emphasis shifted to rate and position cueing. Further, the major cueing activity was focused in the vertical dimension. This strategy was derived from results given in McMillan, Martin, Flach, and Riccio [5]. G-seat vibration cueing was removed completely from the inflatable seat pads and presented via a mechanical seat shaker. In the first experiment, vibration cueing was presented through the seat pads along with acceleration cueing, and it was felt that this may have contributed to "overloading" the g-seat with more information than could reasonably be assimilated.

Tasks

Two tasks were defined and an experiment was performed for each task. The first task was defined as before with an approach, transition to hover, descent and landing. However, the hover portion of the task was altered to force a minimum of 20 seconds in a defined hover. Once pilots entered the defined hover segment, they were required to hold hover and not attempt a landing until given a green light. This procedure corrected problems with data collection in the hover segment during the first experiment. The second task was a 60-second precision hover over the landing deck during which three vertical wind gusts were presented, randomly either up or down.

Factors and Levels

Dynamic seat cueing was included as a factor for both tasks (on or off) while seat vibration cueing via the mechanical seat shaker was a constant condition. Visual delay was included as a factor for the precision hover task only at values of 183 and 117 msec. The 183 msec condition represents one frame less than the 217 msec investigated in the previous experiment. This is the next logical value to examine after determining that 217 msec is unacceptable. A major software update to the aerodynamic model was also tested in this experiment and included as a factor for both tasks (updated model vs. standard model). This factor is referred to as dynamic inflow.

Field of view was included as a factor for both tasks. However, in these experiments, the low level values were based on actual measurements at the now operational SH-60B OFT, as opposed to preliminary design values used in the previous experiment. These values differed from the values used in Performance Experiment I in several respects, most critically in the downward field of view, which was approximately 9 degrees less. In addition, vertical dark areas present in the OFT but not modeled in the first experiment were included in the low level field of view. The high level field of view was the widest VTRS capability, 160 degree horizontal by 70 degree vertical.

Scene detail was included as a factor for both tasks, but in this experiment, the comparison was a VTRS model of the detail available in the SH-60B OFT versus a higher level of detail ship. The primary differences in detail were a VTRS higher detail wake, "pad eyes" on the deck of the high detail ship (an attempt to provide some texture for altitude cueing), plus added antennae and a ladder on the hangar wall of the high detail ship (see Figures 1 and 2). Seastate was used as a difficulty factor for the approach, hover and landing task and pilot experience was categorized as a factor in both tasks. A total of 12 experienced SH-60B pilots participated in the experiments. A summary of the factors and levels in the experiments is given in Table 3.

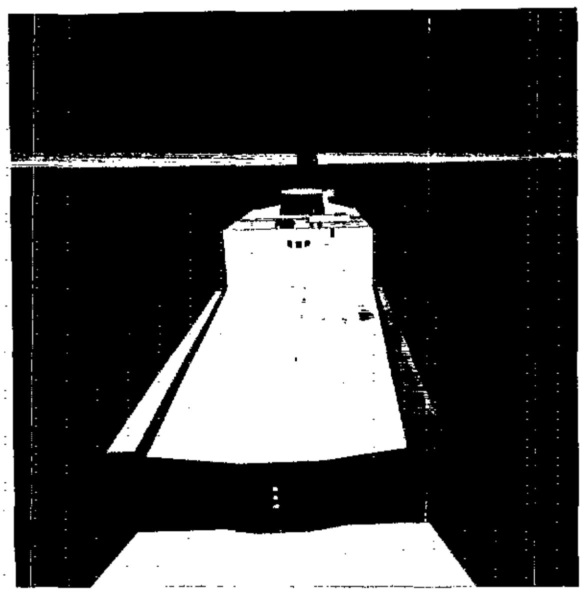

Figure 1. VTRS model of SH-60B OFT visual scene

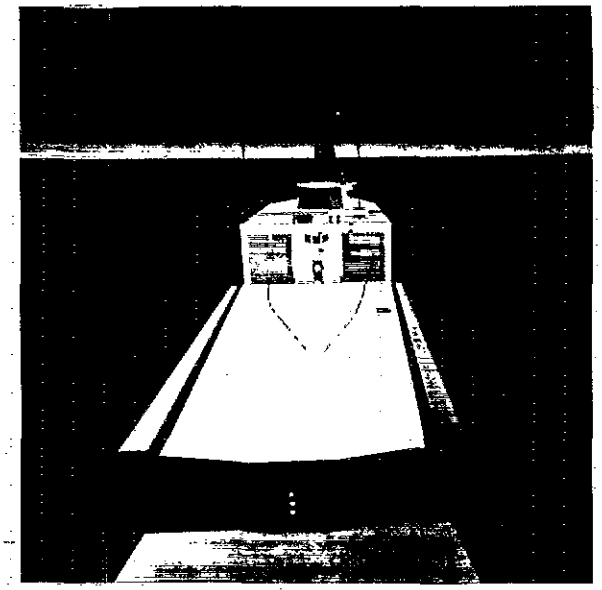

Figure 2. VTRS "high" detail scene.

RESULTS II

Results from the second research effort are summarized in Tables 4 and 5. By far the most striking result is the large field of view effect. In contrast to the fairly small effects that were found in the first experiment, the effects were pervasive (influencing all task segments and many measures) and strongly favored the VTRS wide field of view. Scene detail effects were more modest as expected with the only substantial effect (favoring the higher detail) occurring during the approach segment on lineup control.

The updated aerodynamic model proved beneficial as performance was enhanced for several measures. The visual delay factor had only a small effect on performance, affecting primarily roll activity in the hover, with greater roll variability evidenced with the longer delay. Dynamic seat cueing did not appear to have any meaningful performance effect. Pilot opinion was generally more favorable toward seat cueing than in the first experiment, but pilots still did not favor it over the no seat cueing condition.

DISCUSSION

The problems noted in the first performance experiment appear to have been resolved in the second performance experiment. In particular, problems with procedures for the hover segment were successfully resolved and performance

TABLE 3. SUMMARY OF EXPERIMENTAL FACTORS AND LEVELS

Approach, Hover, and Landing and Precision Hover Tasks

Factor	Level	
Scene Detail	Moderate detail (SH-60B OFT)	High detail (VTRS)
Field of View	Restricted (SH-60B OFT)	Wide (VTRS)
Dynamic Seat Cueing	G-seat Off	G-seat On
Dynamic Inflow	Standard Rotor Aerodynamic Model	Enhanced Rotor Aerodynamic Model

Approach, Hover, and Landing Task Only

Factor	Level	
Seastate	Moderate Seastate (2) and medium air turbulence	Calm Seastate and no air turbulence

Precision Hover Task Only

Factor	Level	
Visual Delay	183 msec	117 msec
Difficulty	Three distinct vertical gust disturbances (counterbalanced combination of up or down)	

TABLE 4. SUMMARY OF EFFECTS FOR THE APPROACH, HOVER, AND LANDING TASK

Factor	Effect Size	Segment/Measurement	Better Option*
Field of View	Large	Effects in all task segments across many measures	VTRS wide field of view
Dynamic Inflow	Moderate/ Small	Effects in glideslope during the approach and altitude control during hover	Enhanced Rotor Model
Scene Detail	Small	Effects in lineup and roll activity in the approach segment	Upgraded VTRS Scene
Dynamic seat Cueing	Small	Did not have a meaningful effect on performance	?
Seastate	Large	Difficulty factor performance was better without seastate	n/a
Pilot Differences	Large	Large control differences	n/a

*The option that resulted in better simulator performance. In cases where quality measures were not affected, no determination of "better" was possible.

TABLE 5. SUMMARY OF EFFECTS FOR THE PRECISION HOVER AND LANDING TASK

Factor	Effect Size	Segment/Measurement	Better Option*
Field of View	Large	Effects in all task segments across many measures	VTRS wide field of view
Scene Detail	Small	Effected pitch control in hover	?
Dynamic Inflow	Small	Response time to gusts	Enhanced model
Visual Delay	Small	Effected longitudinal and vertical positioning and roll activity in hover	117 msec
Dynamic seat Cueing	Small	No meaningful performance benefits with g-seat on	?
Pilot Differences	Large	Large control differences	n/a

*The option that resulted in better simulator performance. In cases where quality measures were not affected, no determination of "better" was possible.

measure inadequacies were also corrected. Procedurally then, and with regard to performance measurement, we are now ready to move into the in-simulator transfer-of-training research phase. G-seat cueing has been pursued through two extensive stages of development and refinement, and still appears to offer no real benefit to performance or even face validity for the shipboard landing task. It would seem that further research with seat cueing for this task is not likely to result in any meaningful pay off.

The large performance effects due to field of view were unexpected in light of the rather small effects observed in the first experiment. There are several probable sources contributing to this difference, the most likely being that the actual measured OFT field of view used in this research effort differed in some critical ways from the preliminary design values for the OFT field of view used in the first experiment. Most importantly, the downward field of view was approximately 9 degrees less for the OFT field of view in the second research effort. In addition, there were two vertical dark areas 5 degrees in width present for the OFT display in the second research effort but not the first. These dark areas are present in the OFT where there are spaces between display screens.

RECOMMENDATIONS

Based on the outcomes from the performance experiments a number of specific statements and recommendations can be made. The following recommendations have direct implications for the design of future transfer-of-training experiments at VTRS and design considerations for the SH-60B OFT:

1. The field of view in the OFT appears inadequate. The downward field of view in the chin window area is probably the most critical and any efforts to upgrade the OFT field of view should start in this area. However, since transfer of training is the ultimate issue in a training environment, not performance per se, final judgment should be withheld until the completion of a transfer-of-training experiment. Due to the large performance effects, and the high cost nature of the issue, it is recommended that field of view be included as a factor in the next in-simulator transfer-of-training experiment.

2. The scene detail in the OFT appears adequate with the exception of the wake. The first experiment gave results clearly indicating that a very low level of detail was not adequate for performing the task, so certainly less

detail than is present in the OFT cannot be recommended. Since this issue has been somewhat resolved on a performance level, there is not a clear need to carry this factor into the in-simulator transfer phase.

3. The aerodynamic model update should be incorporated at the OFT and at VTRS as a constant condition.

4. G-seat cueing should be dropped from further consideration for future VTRS research on helicopter shipboard landing.

5. G-seat vibration cueing should be incorporated as a constant condition at VTRS via the mechanical seat shaker.

6. A visual delay of 217 msec appears too long for this task. A delay of 183 msec is probably the longest delay that should be considered in a visual system for the task. Although performance effects compared to 117 msec are small, it is felt that 183 msec is only marginally acceptable for existing OFTs, and a shorter delay would be recommended for new acquisitions or upgrades of visual systems.

DEVELOPMENT FOR AN IN-SIMULATOR TRANSFER-OF-TRAINING EXPERIMENT

At the present time, planning and development for an in-simulator transfer-of-training experiment is underway at VTRS. The transfer-of-training experimental paradigm brings an additional dimension into focus, namely training. In this environment, not only equipment variables may influence the training process and subsequent transfer, but instructional variables also affect learning and transfer. In fact, previous experience at VTRS has suggested that instructional variables have potential for a greater impact on learning than equipment variables. Further, instructional variables may interact with equipment variables in such a way that equipment costs can be saved if certain instructional strategies are followed. For example, Westra [7] found that the carrier landing task can be more quickly trained under a backward chaining scheme than a whole task (from the abeam position) strategy. It was further determined that if the backward chaining scheme is used, a wide field of view is not necessary for the visual display.

For the experiment under development, the results of the previous performance research have been incorporated, and as a result of this, field of view will be included in the design. No other equipment factors will be directly manipulated since those issues were essentially resolved on a performance basis. However, several instructional variables are under consideration for inclusion in the experiment. These variables are number of training trials, task chaining, and augmented cueing. Task chaining involves segmenting the task and progressively adding segments until the whole task is presented. Thus, the hover and landing phase would be taught first, followed by the transition to hover, hover, and landing, and finally the whole task-approach transition to hover, hover, and landing. Augmented cueing refers to the use of artificial cues in addition to the normal cues already present.

SUMMARY

This paper has attempted to provide an overview of the research program on simulation and training for the helicopter shipboard landing task at VTRS. The overall research strategy incorporating a three phase process and holistic experimental philosophy was presented and discussed. Two major research efforts representing the first phase of research were presented and discussed. It was shown how the research proceeded in a logical manner with results used to build on previous findings and guide succeeding research. The implications of the first phase of research were discussed and it was shown how decisions were made to either make recommendations for simulator design or the next step of the research process. Finally, the development for the second phase of the research program, an in-simulator transfer-of-training experiment, was discussed. The issue of instructional strategies can be investigated in this stage of research, and the implications were discussed.

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