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TECHNICAL REPORT 87-041

SIMULATOR DESIGN FEATURES FOR HELICOPTER SHIPBOARD LANDINGS: II. PERFORMANCE EXPERIMENTS

JULY 1987

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The Vertical Takeoff and Landing Simulator (VTOL) at the Naval Training Systems Center's (NTSC) Visual Technology Research Simulator (VTRS) was used to evaluate the effects of five simulator design features on performance for helicopter shipboard landings. The research was designed to evaluate the effect of current design features of the SH-60B Operational Flight Trainer (OFT), and other design features for training helicopter shipboard landings. The design features investigated were: (1) scene detail (SH-60B OFT scene versus an upgraded scene), (2) field of view (wide versus a smaller SH-60B OFT field of view), (3) dynamic seat cueing (on versus off), (4) dynamic inflow (standard aero model available in existing trainers versus an updated aero model), and (5) visual transport delay (117 msec versus 183 msec).

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19. Abstract (continued)

Twelve SH-60B helicopter pilots performed an approach, hover, and landing task on a representation of an FFG-7 frigate, and a precision hover (over the deck of the frigate) and landing task. The two tasks were performed separately and constituted two independent experiments. Two environmental factors were included. Calm and moderate seastate conditions were used to manipulate task difficulty during the approach, hover, and landing task, and vertical wind gusts were included as a standard feature in the precision hover task. Pilots were separated into low and high experience levels, defined in terms of their shipboard landing experience. (JW)

Results indicated large effects due to field of view and smaller effects due to scene detail, dynamic inflow, and visual delay. All of these results favored the higher fidelity conditions. Dynamic seat cueing did not appear to offer any meaningful positive benefit for performance. Based on these results, recommendations were made for simulator design and for the next phase of helicopter shipboard landing research at VTRS. The next phase of research will involve an in-simulator experiment which is now under development. The research reported here concludes the first phase of research involving performance experiments at VTRS.

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INTRODUCTION

The effectiveness of simulation for training aviator skills has become a recurrent theme in the training literature (1,2). The trend toward extensive use of simulation to meet operational training requirements is likely to progress due to the major impact of cost, availability, and safety issues in the use of training aircraft (3). Furthermore, recent technological advances have provided a wide variety of design options that can substantially increase simulation fidelity and, conceivably, training effectiveness. However, increases in the fidelity of simulation do not necessarily guarantee increases in training effectiveness and are generally accompanied by increases in cost. Therefore, it is important to evaluate the utility of advanced design options to facilitate informed procurement decisions and to provide optimal, cost-effective pilot instruction.

The major research effort at the Visual Technology Research Simulator (VTRS) at the Naval Training Systems Center (NTSC) has been to experimentally evaluate simulator design options and training procedures for a wide variety of flight tasks. This research serves as guidelines for: (1) the procurement of design options for flight simulators and (2) the development of instructional procedures to achieve optimal training effectiveness. Experiments have previously been conducted at VTRS on simulator requirements for the carrier landing task (4,5) and air-to-ground attack scenarios (6,7). With the recent installation of a vertical take-off and landing (VTOL) simulator at the VTRS, design and instructional issues for helicopter shipboard landing operations are now being examined.

A current VTRS research effort has focused on the evaluation of design features for a training simulator to support the acquistion of skills needed to execute helicopter landings on small ships. As part of this effort, the VTOL cockpit was configured to replicate the SH-60B (the Navy's LAMPS MK III anti-submarine warfare helicopter) and a computer-generated image of an FFG-7 frigate capable of real-time translations through a variety of seastate conditions has been implemented.

The LAMPS MK III community has raised questions regarding possible improvements in their present Operational Flight Trainer (OFT). Some of the suspected problem areas in current OFT simulation of the shipboard landing include the presence of a potentially excessive visual transport delay, a restricted Field of View (FOV), and the lack of detail in the visual display. Since helicopter landings on small ships, particularly under adverse conditions (e.g., in high sea states and/or at night), present severe and potentially life-threatening tests of a pilot's skills, it is essential to insure that adequate training is provided. Simulation represents a significant portion of that training. Therefore, the purpose of this research was to evaluate simulator features of potential use in training this task.

RESEARCH APPROACH

Research at VTRS has employed a three-phase approach (8). The first phase involves performance experiments in which pilots who are proficient in the task are tested under a variety of experimental conditions to provide information concerning the absolute and relative effects of experimental factors. Phase two experiments utilize paradigms in which pilots who are not proficient in the task are provided with training under one of several experimental conditions, and are subsequently tested on a criterion condition in the simulator. The third phase involves a transfer-of-training paradigm in which the effects of prior training in the simulator are tested by assessing task proficiency in the operational environment.

A first phase performance experiment concerned with helicopter shipboard landing was recently conducted at VTRS (9). Six simulator design features were tested in the experiment, each with two levels representing high- and low-fidelity options. These were: (1) scene detail (high-detail deck, hangar, and seascape information versus degraded deck, hangar, and seascape information), (2) FOV (VTRS-wide versus SH-60B OFT field of view), (3) system visual lag (transport delay) (117 msec versus 217 msec), (4) g-seat acceleration cueing (on versus off), (5) g-seat vibration cueing (on versus off), and (6) auditory cueing of main rotor amplitude, main gear box, and auxiliary gear box sound as a function of collective position and vertical acceleration (on versus off).

All factors were tested across two levels of seastate/turbulence and pilot experience. At the lower level of seastate/turbulence, there was no ship motion other than a 10-knot forward movement, and no air turbulence affecting the aircraft. At the higher level there was ship motion in the roll, pitch, yaw, sway, and heave dimensions that approximately corresponded to effects expected from moderate seas (i.e., from waves averaging 0.55m in height). In the active seastate condition, air turbulence affected aircraft stability on the vertical, lateral, and longitudinal axes. Although all subjects in the experiment were experienced helicopter pilots, they were classified as either more or less experienced based on their cumulative hours of rotary wing flight.

In summary, scene detail had the largest effect on performance measures obtained during the approach, hover, and landing segments of the task, with better performance observed under the high-detail condition. The manipulation of visual system delay and field of view had small effects on performance, while the two g-seat factors and collective sound had essentially no effect. Effects of pilot experience on task performance were negligible. However, several deficiencies in equipment function and pilots' performance of the task made interpretation of a portion of the results difficult. Specifically, the g-seat used to provide acceleration cueing was reported by pilots in the experiment to be distracting. Information specifying self-motion obtained from the visual display and the activity of the g-seat appeared to be unrelated. Secondly, a large proportion of the landings did not contain a definable hover segment, i.e., pilots often did not maintain a hover over the ship's deck before landing.

The experimental strategy for the present experiment constituted an attempt to clarify issues raised by Westra and Lintern's (9) results and to investigate the effect on pilot performance of several design features of the SH-60B OFT currently used to train helicopter shipboard landing. Since the hover segment is considered to be among the more critical components of helicopter shipboard landing, two separate tasks were performed in the experiment. The first involved an approach, hover, and landing, while the second involved the execution of a precision hover and landing.

EXPERIMENTAL ISSUES

Scene Detail

Scene detail emerged as the most important experimental factor in Westra and Lintern's (9) experiment in terms of its affect on pilots' performance. Pilots' ability to maintain heading along the centerline of the ship during the approach phase of the task, as well as maintaining position over the desired landing point during the hover and touchdown phases, was significantly better with the high-detail scene. The deck and hangar markings, in combination with the ship's wake and seascape texture, appeared to provide effective information specifying lineup, position, and drift.

Pilots have indicated that they attend to specific visual features while monitoring their position and orientation relative to the ship and sea from the initial phase of tracking the ship to the final phase of touchdown (10). Many of these features consist of markings and reference points located on the hangar wall or ship's deck which convey very distinct spatial information. Vertical lines on the hangar wall, for instance, are used to monitor lateral drift during hover.

There are a number of potential scene detail manipulations for consideration in helicopter shipboard landing research. Varying levels of seascape detail (texture density), presence and absence of a ship's wake, and other perceivable ship features may affect both the approach (lateral position and glideslope tracking) and hover segments of the landing task. The absence of a ship's wake, and the lack of optical discontinuities in the surrounding seascape in Westra and Lintern's low-detail scene, may have been the major contributors to increased lateral error during the approach phase of the task, when compared to the high-detail scene.

Texture density and scene content on and around the surfaces of the ship may also be important elements in the performance of the hover and touchdown segments. Hettinger and Owen (11) obtained results indicating that the detection of loss in altitude is strongly influenced by the density of perceivable surface features. In a manner related to visual contrast sensitivity (12), accuracy in detecting descent deteriorates when the number of perceivable surface features (edges) per degree of visual angle is too small or, alternatively, too large. Optimal sensitivity occurs in a mid-range of values for texture density. Therefore, evaluating pilots' performance by varying levels of texture density on the ship's deck (e.g., cross-hatched patterns) and in the seascape (e.g., isolated patches of contrasting shades of blue) may provide useful information relative to optimizing scene content for supporting pilot performance.

Manipulating the availability of deck and hangar features to determine the sources of information most likely to affect hover and landing performance represents another potential scene detail factor. Although it is not possible to address all of the above visual issues in a single experiment, a variation in scene detail was included as a factor in the current experiment.

The manipulation of scene content employed in the current experiment involved a comparison of performance obtained with two dusk scenes, one of which is representative of the visual scene (FFG-7) currently available in the SH-60B OFT, versus an upgraded version of the FFG-7 available at VTRS. The VTRS scene included an increase in contrast of the deck and hanger wall markings, additional deck markings, and a more realistic depiction of the ship's wake.

Dynamic Seat Cueing

G-seats represent a relatively new technology in helicopter simulation. Consequently, few studies with helicopter g-seat cueing have been performed and results concerning their utility for simulation have been inconclusive. For example, in an experiment conducted by Ricard, Parrish, Ashworth, and Wells (13), there was an approximate five percent reduction in error (combined deviation in the x, y, and z dimensions relative to the desired hover location) when g-seat cueing was contrasted with fixed-base simulation in the performance of a precision hover task. Although the effects of adding a g-seat were minimal, this was partially attributed to the short development time of the software to drive the seat. The seat may not have been scaled properly to respond to the range of cues expected in helicopter operations and further development was recommended.

Westra and Lintern (9) independently tested g-seat acceleration cueing and g-seat vibration cueing and found no meaningful effect on performance. However, the pilots who participated in the experiment felt that the g-seat acceleration cueing was not working properly and was, in fact, somewhat disruptive. These results indicated a need for further engineering development prior to any further evaluation. Thus, a number of changes were made to the g-seat hardware and software prior to the current experiment.

The duration of this development was guided by test pilot comments and results obtained by McMillan, Martin, Flach, and Riccio (14). They found that for a roll axis tracking task, a g-seat providing position and velocity cueing resulted in a performance benefit nearly equal to a full motion platform. Since the major control activity is in the vertical dimension for the hover portion of the helicopter shipboard landing task, this drive philosophy was applied with emphasis in the vertical dimension.

G-seat vibration cueing was well accepted by the pilots in the Westra and Lintern (9) experiment and it was recommended that this cueing be retained. Vibration cueing provides the basic 17 Hz rotor vibration, plus it provides translational lift vibration when the aircraft decelerates from approximately 25 to 20 knots. However, this cueing was presented through the inflatable seat pads along with acceleration cueing. As part of the developmental strategy, the g-seat vibration cueing was removed completely from the seat pads and presented via a mechanical seat shaker.

Field of View

The task of determining an optimal, cost-effective visual system FOV for the simulation of helicopter shipboard landing remains unresolved. Given the unique visual requirements of this task, there are two primary concerns involved in determining an effective FOV. The first concerns the size of the FOV in degrees of visual angle, and the second concerns the placement of visual imagery (i.e., determining the relative merits of providing visual information in the side window, chin window, etc.).

The second issue is particularly relevant to the helicopter shipboard landing task. The demands of this operational environment, particularly during the hover and landing segments, require that the pilot be provided with an adequate lower FOV. A pilot's attention in these two phases of the task is largely directed toward acquiring visual information from the surface of the ship's hangar wall and deck through the chin window(s) and lower portion of the forward and side windows.

Ricard et al. (13), used a 36 degree vertical by 48 degree horizontal FOV, exclusively. All pilots in their experiment commented that a wider FOV would have made performance of the shipboard hover task easier, and particularly stressed the need for the peripheral visual information that a side window would provide. Gracey, Sommer, and Tibbs (15) examined helicopter landing performance in an open field using a closed-circuit television system in which the size of the FOV could easily be manipulated. They found no evidence that a limited FOV hampered performance, although peripheral and lower field visual information may not be as critical in an open field landing as it is in shipboard landing. The acceptable margin of error in performing the former task is likely to be far greater than in the latter.

Westra and Lintern (9) employed two fields of view in their experiment, the larger representing the FOV available at VTRS, and a smaller representing an SH-60B OFT FOV. The OFT FOV provided 10 degrees less coverage in the downward right field than the VTRS field of view (see Fig. 1). Perhaps because of this lack of lower FOV coverage, average vertical velocity at touchdown was significantly greater with the smaller as compared to the larger FOV. Because of the importance of field of view for effective training of the helicopter-shipboard landing task, an additional evaluation between the VTRS FOV and the SH-60B OFT FOV was included in the current research effort as an experimental factor. In addition, the OFT FOV simulated at the VTRS was further refined to provide a more accurate representation of the OFT FOV, including the gaps between the visual display monitors in the OFT. In Westra and Lintern's (9) experiment, the values used to model the simulated OFT FOV was based on preliminary OFT design specifications (Fig. 1). In the present experiment, the values used to model the simulated OFT FOV were based on actual measurements taken in the OFT by VTRS engineering staff, and included the gaps between visual monitors. These values differed considerably from the OFT values used in the Westra and Lintern (9) experiment.

Visual Transport Delay

Visual image generation introduces unavoidable transport delays in simulators due to the lengthy computation process involved. Visual transport delay is defined here to be the time period from stick input to the completion of the first field of video output. A substantial accumulation of empirical

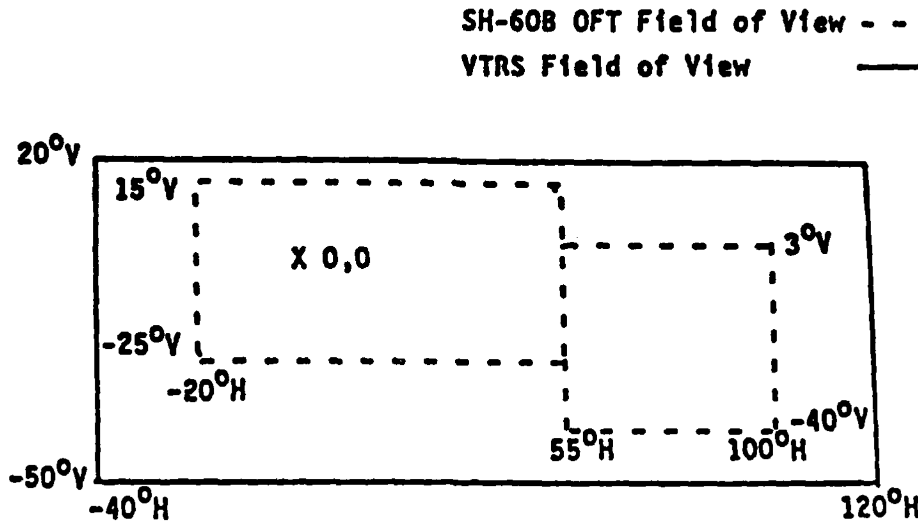

Figure 1. Experimental levels of field of view for the Westra and Lintern (9) experiment.

findings indicates that increased lag conditions contribute to deteriorated operator performance (16,17). Westra and Lintern (9) contrasted visual transport delays of 117 and 217 msec, and obtained results indicating a performance advantage for the shorter lag condition in the hover, descent, and touchdown segments of the helicopter shipboard landing task. Specifically, the shorter delay resulted in reduced longitudinal variability during hover, reduced lateral activity of the cyclic during descent, and reduced vertical velocity at touchdown. Ricard et al. (13) contrasted delays of 68 and 128 msec and reported significantly lower error rates on all their measures of helicopter shipboard landing performance with the shorter delay.

The current experiment also investigated the effects of visual transport delay, but concentrated on its effects during the hover segment of the shipboard landing task. In this phase of the task there is a greater demand for precise control inputs as the acceptable margin of error for positional deviation decreases rapidly when the helicopter comes into closer proximity with the surfaces of the ship.

Dynamic Inflow

The aerodynamic characteristics of helicopter rotors are complex phenomena. Assumptions are required to simplify rotor models for practical real-time simulation applications. A common simplification applied to helicopter flight training simulators is to treat the rotor system as a disk because this requires less computational power than modeling individual blades. The aerodynamic forces on any helicopter rotor disk can be expressed as functions of the blade collective pitch angle and the primary velocity components. The conventional formulation of these velocity components defines one component as advance ratio and the other as inflow ratio. Advance ratio consists of rotor tangential velocity components divided by rotor rotation speed. Inflow ratio consists of the velocity component flowing vertically through the rotor divided by rotor rotation speed. The vertical velocity component through the rotor has two sources: the actual vertical motion of the vehicle and the velocity induced on the flow field by the passage of the rotor blades. Rotor induced velocity is readily apparent in the real world as the downwash felt when a helicopter hovers overhead. Some commonly used simulation models of rotor disks do not properly account for the transient behavior of induced velocity changes whenever state changes occur such as pilot control inputs or external disturbances. The SH-60B simulation model originally implemented in the VTOL simulator at VTRS is typical in that induced velocity changes and subsequent rotor thrust changes respond "in toto" the instant rotor state changes. In reality, time is required for the flow field around each blade to change. Therefore, the concept of dynamic inflow was introduced to the SH-60B rotor model to provide the transient behavior of rotor induced velocity and the subsequent behavior of rotor thrust.

The primary manifestation of dynamic inflow apparent to a simulator pilot will be a more representative behavior of helicopter vertical response to his collective inputs. With dynamic inflow, initial response to pilot collective will be rapid and then moderated as the change in rotor thrust is attenuated by the inflow transient. This response characteristic is representative of real helicopters and is expected by experienced pilots. Without dynamic inflow, initial response is not attenuated and simulator pilots must provide the attenuation they expect from real flying experience by manually reducing the collective input or by learning to make smaller control inputs in the simulator. Such unrepresentative control actions are objectionable to pilots and are a contributing factor in persistent complaints of poor fidelity and user acceptance in helicopter training simulators, particularly for low altitude, low speed tasks such as hovering and landing on small ships.

The dynamic inflow model utilized in this experiment was originally developed and subjected to limited testing at Singer-Link as a modification to their standard disk rotor model. After implementation in VTOL, refinements were developed by VTRS staff members to eliminate anomalies which appeared as more experience was gained in representative flight tasks with a wide angle visual scene. The parameter values used in the VTRS experiment were determined by attempting to match limited flight test data and pilot evaluations. High quality time history flight test data from H-60 series helicopters is needed to guide model refinement toward true flight fidelity. Inadequate flight test data is a common problem for simulating helicopter dynamics which limits the potential fidelity of all simulators regardless of how rotor dynamics are modeled. Rotor disk models utilized by training simulator manufacturers other than Singer-Link have the potential for including dynamic inflow effects. Therefore, the effects of dynamic inflow revealed in this experiment are applicable to all helicopter training simulators currently in the military inventory and in the acquisition stages.

METHOD

Repeated-measures experimental designs were used to investigate the effects of five simulator design features on the performance of experienced pilots in the simulator. Pilots performed an approach, hover, and landing task on a representation of an FFG-7 frigate in a simulated SH-60B helicopter, and a precision hover (over the deck of the frigate) and landing task. The two tasks were performed separately and constituted two independent experiments.

SUBJECTS

Twelve experienced SH-60B helicopter pilots from Helicopter Sea Control Wing 3, Mayport, Florida participated in the experiment. All pilots routinely flew VTOL aircraft in helicopter/ship operations. The pilots averaged 1180 hours of total flight time and varied in overall experience with a range of 200 to 3000 rotary flight hours. Table 1 summarizes the flight experience of the pilots.

TABLE 1. SUMMARY OF PILOT EXPERIENCE

Pilot #	Total # Rotary Flight Hours	# Shipboard Landings	Experience Level*
101	1300	400	High
102	1275	420	High
103	299	22	Low
104	200	20	Low
105	1430	500	High
106	1000	175	Low
107	480	30	Low
108	1005	195	High
109	1390	200	High
110	950	50	Low
111	3000	1000	High
112	400	70	Low

* High experienced pilots averaged 452 shipboard landings
Low experienced pilots average 61 shipboard landings

APPARATUS

The VTOL simulator at VTRS consists of a cockpit which is representative of the Navy's SH-60B Seahawk helicopter, a wide-angle visual system and a pneumatically actuated g-seat with buttock, thigh, and lower back cushions to simulate tactile pressures experienced during flight. The cockpit is mounted on top of a fixed platform and enclosed in a spherical (34 ft diameter) dome.

The cockpit is provided with instrumentation and controls for the pilot's right seat. All basic aircraft systems for flight control and guidance are simulated with limited navigation and emergency procedures.

The visual scene, a depiction of an FFG-7 frigate at sea under dusk illumination, was produced using computer-generated imagery and was projected onto a 17 ft radius screen. A General Electric Compu-Scene ' (upgraded to the extra edge capacity of a Compu-Scene III) and a PDP 11/55 minicomputer were used to provide a 4000-edge capacity for scene generation. Two full-color TV light valve projectors (1025 lines) were used to display the imagery in adjacent fields. Aerodynamic and visual subsystem computations were computed at a 30 Hz iteration rate by an SEL 32/77 minicomputer system. Cyclic, collective, and directional pedal control loading were provided by a McFadden variable force control loading system. Aircraft and environmental sounds were also simulated. Herndon (18) provides a more complete description of the VTRS helicopter simulator.

Experimenter/Operator Station

An experimenter stationed at the Experimenter/Operator station (EOS) controlled the presentation of individual trials by entering predetermined event and initial configuration parameters. The experimenter was also able to communicate with the pilots via an audio headset. Two color monitors displayed the background and the target (Frigate) image and provided the experimenter with an approximate representation of what the pilot was viewing in the simulator.

Two graphics monitors provided the experimenter with information concerning pilots' performance. One display provided a real-time representation of the major cockpit instruments, and the other provided a real-time graphic illustration of the location of the helicopter relative to the landing deck beginning 1000 ft from the ship to touchdown. The display also provided touchdown-accuracy information (lateral and longitudinal distance from the Rapid Securing Device) to the experimenter who relayed this information to the subject at the conclusion of each trial.

EXPERIMENTAL TASKS

In fleet operations, the approach to landing is flown from directly astern the ship, along a 3.5 deg. glideslope, until the aircraft is within approximately 10 ft (3.05 m) of the ship's stern. At this point, the descent is stopped and the aircraft is maneuvered across the stern to a point approximately 15 ft (4.75 m) above the designated landing spot. The pilot adjusts aircraft speed to match that of the ship and a hover is maintained until the pitch, roll, and yaw of the ship are momentarily stable. The pilot then descends to the landing deck and the aircraft is secured for a free deck landing.

In the approach, hover, and landing task the simulator was initialized with the helicopter at an altitude of 150 ft, 1800 ft behind the ship, at an airspeed of 45 kts, and a descent rate of approximately 136 ft/min. The aircraft was initialized on glideslope (3.5 deg) and lineup. The ship was heading north at a speed of 10 kts. Upon release from freeze, pilots initiated a descending and decelerating approach to the ship, transitioned to a hover near the stern, hovered over the designated landing area, and finally executed a descent to the landing surface.

In the precision hover task, the simulator was initialized with the helicopter at an altitude of 45 ft, 100 ft behind the ship, airspeed of 10 kts, and a descent rate of approximately 18 ft/min. The aircraft was initialized on glideslope and lineup. The ship was heading north at a speed of 10 kts. Upon release from freeze, pilots transitioned to a high hover over the port Rapid Securing Device (RSD), maintained the hover over the RSD until the deck status light signaled the end of the timed hover segment, then proceeded to touchdown.

In each task, a "Deck Status Light" (DSL), mounted on the starboard side of the ship's hangar wall, provided information to the pilots regarding the maintenance of a hover position over the deck. The DSL remained green until the center of gravity of the aircraft crossed into a 14 ft radius of the port RSD. At this point, the DSL transitioned to amber for 20 sec in the approach, hover, and landing task, and 60 sec in the precision hover task. Pilots were instructed to maintain a hover 12 ft over the deck during this time. Following this interval, the DSL transitioned to green, informing the pilots that they were cleared to land.

EXPERIMENTAL FACTORS

Five simulator design features were selected as independent variables for this experiment. Four simulator design features (scene detail, FOV, dynamic seat cueing, and dynamic inflow) were used in both experimental tasks. The fifth simulator design feature (visual transport delay) was used only in the precision hover task. Two environmental factors were also included in the experiment. For the approach, hover and landing task, factors were tested across two levels of seastate (calm versus moderate). Vertical wind gusts were included as a standard feature in the precision hover task. Experimental factors and levels for the two tasks are summarized in Table 2.

Scene Detail

The moderate-detail ship was a VTRS model of the scene detail available in the Navy's SH-60B (LAMPS) OFT. The representation of the ship included deck and hangar markings, a glideslope indicator (GSI), a horizon reference bar, a DSL, and a wake (Fig. 2). The high-detail scene represented an upgraded version of the OFT scene. The high-detail ship included all the features of the OFT scene along with masts, the representation of tracks on the deck used for transporting helicopters into the hangar, and additional deck markings intended to represent pad eyes (tie-down fixtures embedded in the deck, Fig. 3). An enhanced depiction of the ship's wake was also included in the high-detail ship.

Field of View

An evaluation of the contribution of FOV parameters to pilot performance constituted a second factor included in both tasks. The VTRS wide FOV was contrasted with a smaller FOV representing the SH-60B OFT FOV (Fig. 4). The values used to model the OFT FOV were based on actual measurements taken in the OFT by VTRS engineering staff. These values differed considerably from the OFT values used in the Westra and Lintern (9) experiment which were based on preliminary OFT design data. The actual OFT values used in this experiment are given in Fig. 4 and can be contrasted with the stated values in Fig. 1.

TABLE 2. EXPERIMENTAL FACTORS

Approach, Hover, and Landing and Precision Hover Tasks

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

Approach, Hover, and Landing Task Only

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

Precision Hover Task Only

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

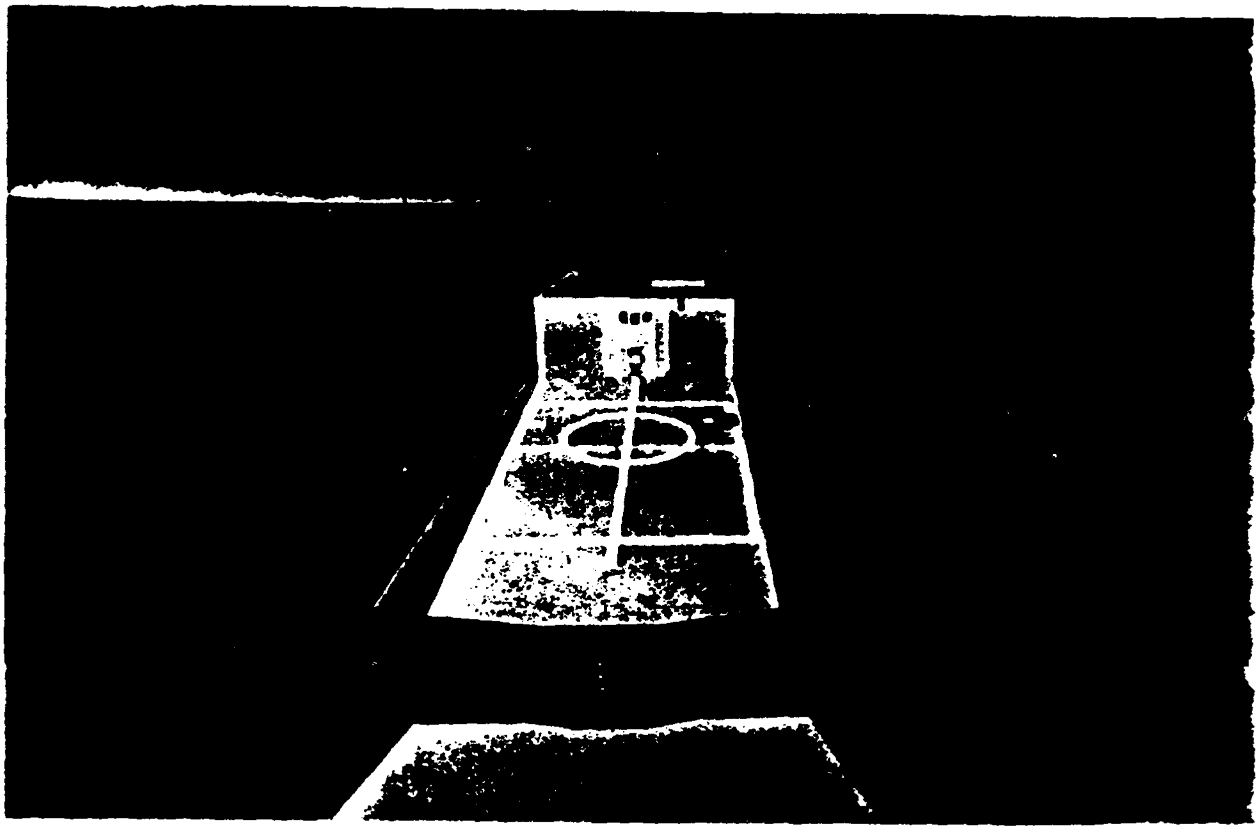

Figure 2. SH-60B OFT visual scene.

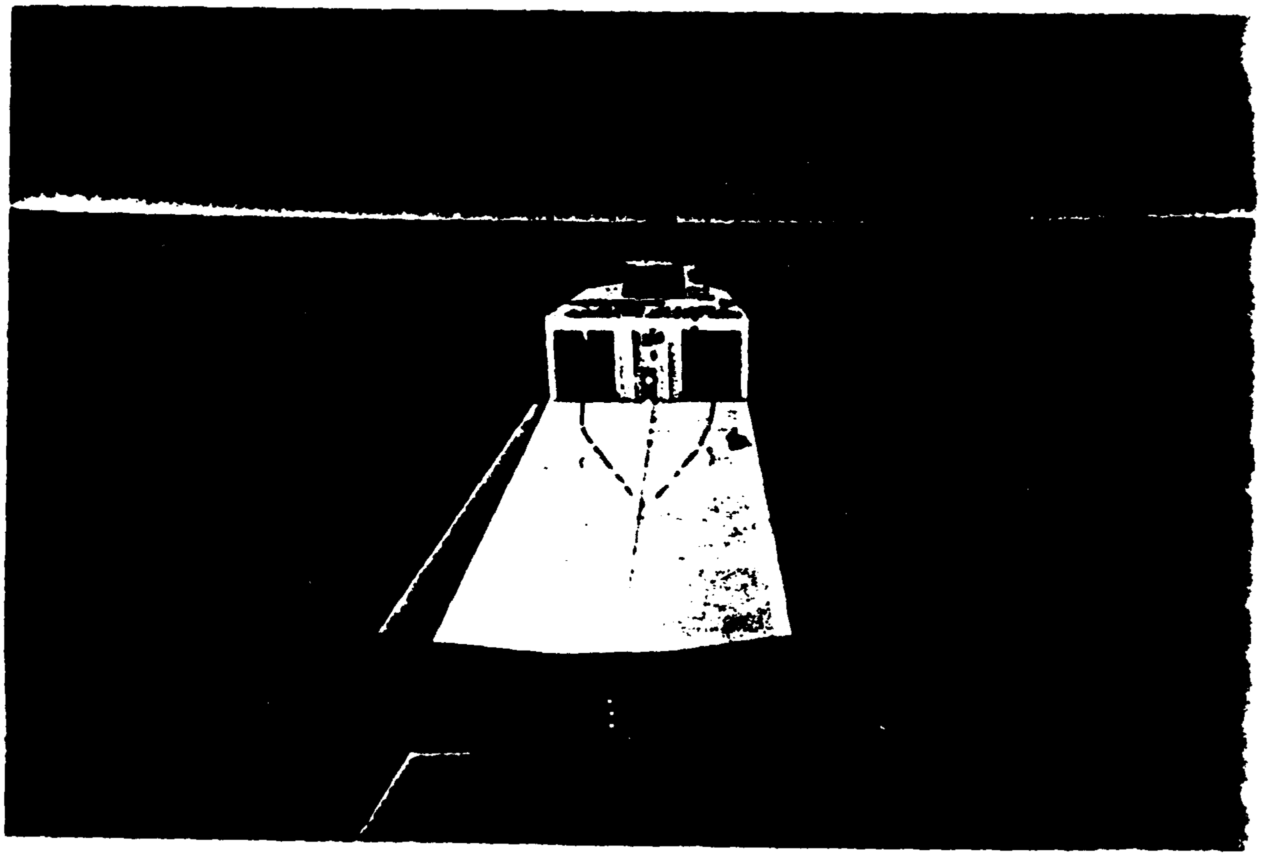

Figure 3. Upgraded VTRS visual scene.

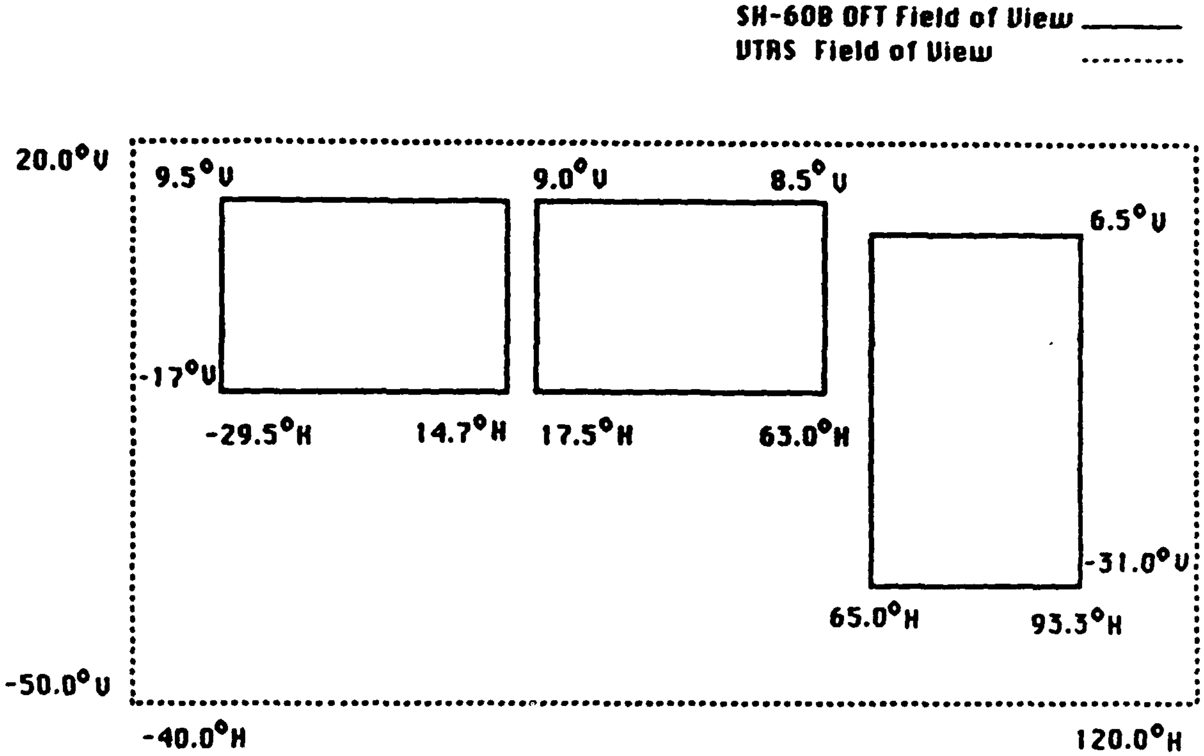

Figure 4. <u>OFT and VTRS experimental fields of view</u>.

<u>Dynamic Seat Cueing</u>

Software for driving the g-seat was refined and upgraded by VTRS engineers in response to the results from the Westra and Lintern (9) experiment. Selected drive philosophy for the seat was as follows for the current experiment:

- To drive the large bladder down for plus normal G and up for minus normal G to create a vertical eye shift with respect to the cockpit and visual scene.
- To make the top four bladders harder for plus normal G and softer for minus normal G to simulate compression into the seat and normal lifting out of the seat.
- The seat pan was also driven by roll angle and roll velocity. Right roll resulted in left side up and right side down by roll angle for low G flight such as hover. Roll velocity was added as a drive in the same direction to create a response to acceleration that is slower than the actual acceleration itself, since this appeared to be a nearly unanimous request by pilots. The pitch angle and pitch velocity pitched the seat pan forward and aft.
- The backrest was driven in the same manner as the seat pan by roll and pitch angles and positions. Z acceleration was used to drive the backrest forward for plus Z to harden it, and backward for minus Z to soften it. This effect is chiefly due to the tilt of the seat.

X acceleration was not used due to the relatively low X acceleration on the approach, hover, and landing modes. The seat drive levels in response to each aircraft position, velocity, and acceleration were set by experimentation with SH-60 pilot comments.

A brief description of the VTRS motion seat hardware is given in Appendix A. G-seat vibration cueing was presented as a constant condition via a mechanical seat shaker which was placed in the back of the seat. This was in contrast to the Westra and Lintern (9) experiment in which the vibration cues were presented through the inflatable seat cushions.

Dynamic Inflow

A major upgrade to the flight dynamics software of the VTOL SH-60B incorporates an enhancement to the rotor aerodynamics model referred to as dynamic inflow. This feature is considered to be more representative of the actual helicopter than standard rotor models available in existing training devices. Simulation of the dynamic inflow phenomena is designed to produce a more accurate representation of the vertical responses of the helicopter as produced by collective inputs. This updated aerodynamics rotor model was compared to the original aero model without dynamic inflow.

Visual Transport Delay

For the precision hover task only, two levels of visual transport delay (117 msec versus 183 msec) were used to determine the effect on pilot performance of delayed visual feedback following control inputs. Westra and Lintern (9) used 217 msec for the longer condition and determined that this was unacceptable. The value of 183 msec used in this experiment represents one less computation frame length.

Experience Level

Although all subjects in the experiment were experienced helicopter pilots, they were classified as either more or less experienced based on their shipboard landing experience. Pilots categorized as less experienced had an average of 61 shipboard landings, while pilots categorized as more experienced averaged 452 shipboard landings (Table 1).

Seastate

For the approach, hover, and landing task only, two levels of seastate conditions were used. One level of this factor represented calm sea conditions with no concurrent air turbulence. The other level represented a moderate seastate (seastate 2) acting on the ship's axes with concurrent turbulence acting on the aircraft corresponding approximately to that expected with the given seastate. A seastate of two represents conditions typical of waves averaging 0.55 m (1.8 ft) in height. Seastate turbulence was quieted as the pilot crossed the stern of the ship to facilitate landing within a reasonable period of time. Quieting decreased the random amplitude factors (random values that determine amplitude of ship roll and heave) acting on ship motion, both longitudinally and latitudinally by 70%. Thus, for a seastate of two, the random amplitude factors were 0.0, 1.117, and 3.035. As the pilot crossed the stern of the ship, the random amplitude factors were reduced to 0.0, 0.35, and 0.9105.

Wind Gusts

Wind gusts were introduced in the precision hover task in order to produce a high workload environment, and to allow measurement of response time and the frequency and amplitude of pilots' collective, cyclic, and pedal control inputs. Each 60 sec hover segment contained three distinct vertical gust disturbances (either straight up or straight down). The wind gusts were each five seconds in duration with a magnitude (force) of six ft/sec. The gusts were administered (either up or down) at the 15-, 25-, and 35-second time period of the 60-second hover segment. Wind gust direction was counterbalanced in the experimental design, but appeared random to the pilot.

PERFORMANCE MEASURES

Raw data were recorded at 30 Hz and then reduced to a set of trial summary measures. Various parameters of aircraft states were sampled in the simulator and used to derive trial-summary measures of a number of dimensions of performance. For measurement purposes, data was summarized across the approach, hover, and descent segments of the task. A large number of summary measures were computed including Root Mean Square (RMS) error, mean (algebraic) error, and variability around those means for key task dimensions (e.g., lateral error during hover). Time-on-tolerance (TOT) summary scores were also calculated for several tolerance bands. These TOT scores were used extensively in results presentation as an aid in interpreting results. They are particularly useful in cases where operationally important tolerance bands can be defined because effect values can be read directly as percentage (of TOT) differences. Westra and Lintern (9) provide a description of the basic measure set on which the measure set for the current experiment was largely based. Additional measures included the TOT scores mentioned above, and response time to the wind gusts presented in the precision hover task. Also, raw data to support frequency decomposition (power spectral density) of aircraft stick and other states were collected.

Criterion-referenced quality indicators were emphasized in the data analysis for this experiment. The preselected or a priori set of quality measures were: (1) RMS error and TOT of aircraft position relative to the desired flight path during the approach, hover, and descent, and (2) absolute error of the aircraft state from that desired at touchdown. In addition, inspection of data summaries suggested that measures of stick movement, aircraft activity, and bias and variability components of task outcome would also be informative. Results of these analyses are presented only for measures showing meaningful effects that did not correlate highly with other measures. Redundancy was determined by examining correlations between measures. Generally, if a correlation between measures was higher than 0.9, only one of them was analyzed. The measures chosen in this manner represent a posterior set since they were selected from a larger set on the basis of effect size. Although nominal significance levels used for examination of these measures were the same as those used for the a priori set, caution is advised in interpretation since the posterior set will have higher true alpha levels.

PROCEDURE

Twelve experienced naval helicopter pilots were selected to visit VTRS. Each pilot was assigned to one of the experimental sequences and received a written briefing on arrival at VTRS. The briefing described the experiment, procedures for performing the tasks, and several important features of the SH-60B simulation. Pilots were also shown the cockpit of the simulator and the relevant controls were identified and described.

Each pilot received 16 preliminary trials under several experimental configurations before beginning an experimental sequence. The pilots were subsequently cycled through their simulator sequence to complete 32 approach, hover, and landings and 32 precision hover trials. Trials were administered over three days in sessions of eight trials each. Pilots alternated experimental sessions in order to minimize effects of fatigue. Experimenters monitored the simulator trials throughout the experiment from the EOS and gave feedback (i.e., distance from RSD) after each trial. Pilots were debriefed and completed a questionnaire at the end of the experiment.

EXPERIMENTAL DESIGN

The two experiments were organized as repeated-measures designs with each pilot executing one-half of a full-factorial for each experiment. The combination of two levels of five factors in each experiment resulted in thirty-two unique combinations or experimental conditions. Thus, each pilot performed on sixteen conditions of each experiment, with each pair of pilots completing a full factorial. Since each pair of pilots completed a full factorial, the full factorial for each experiment was repeated six times across the twelve pilots who participated in the experiment.

The replications have been taken advantage of to achieve balance against trends (linear, quadratic, cubic) and carryover which was not achieved within pilots. Each pilot also performed two (consecutive) trials per condition to obtain an estimate of within-subject variability and to provide some additional balance against certain types of carryover. In summary, each pilot performed two tasks, sixteen experimental conditions per task, two trials per condition, plus familiarization trials prior to the experimental trials.

In addition, the eight possible wind gust conditions were added to the design of the hover task so that maximum balance against order effects would be obtained, and to prevent the pilots from "learning" the order of presentation. Pilots were also separated into low and high experience groups which was incorporated into the experimental design by partitioning on the full factorial replications.

RESULTS

DATA ANALYSIS

The analysis-of-variance summaries show the mean differences between levels of factors as well as η^2 (i.e., the proportion of the total variability that is accounted for by a specific factor[1]). The two-factor interactions were separated into four groups in the approach, hover and landing task, and three groups in the precision hover task and tested omnibus fashion. For example, the five two-factor interactions involving the pilot-experience factor were summed into the single term indicated on the tables. The total sums of squares accounted for by the sets of two-way interactions, divided by the total degrees of freedom involved, was compared to the residual mean square for tests of significance. Although these omnibus terms are shown in the tables for convenience, each estimable two-way interaction was examined individually and will be discussed where necessary.

Primary Contrasts

Main effects were tested against a single residual mean square term except in the case of a significant pilot by equipment factor interaction. Variance due to pilot differences has been removed from main effects as a convenient consequence of the repeated-measures experimental designs. The residual term is composed of all sources of variance except the main effects and the two-way interactions. This includes all the three-way and higher-order interactions as well as all trials and replication effects. A large portion of the residual term estimates the within-subject, trial-to-trial variability. The use of a pooled residual term is appropriate only if the pilot interaction with that factor is small. Otherwise, the main effect must be significantly larger than the interaction for the main effect to be generalizable to the population of helicopter pilots (19). This was taken into account where necessary for all analyses, and the significance values indicated correctly reflect this. Thus, in some cases, an effect involving a significant pilot interaction may not be significant while a smaller effect not involving a significant pilot interaction may be significant.

Two-way Interactions Involving Pilot Differences

Pilots were differentiated in the experiment on the basis of their flight experience. Thus, interactions of flight experience with other factors pose no problem for the analyses. Such an interaction requires that the factor effect in question be interpreted in relation to experience, and that it be generalized only to a population of pilots classified similarly in terms of experience. Within experience level, subject-by-factor interactions that are independent of experience-by-factor interactions are also possible. They suggest the existence of a pilot classification that could impact interpretation of the relevant factor. Nevertheless, because that classification has not been identified in the experiment, it is not

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[1] More correctly, η^2 is the proportion of the total sums of squares of a dependent variable that is associated with group membership or designated by an independent variable.

possible to modify interpretation of factor effects on the basis of those pilot characteristics, and the subject-by-factor interaction must be viewed as unexplained error variance. In such a case, a factor effect must be significantly greater than the subject-by-factor interaction for it to be generalizable to the population of pilots. However, the existence of the interaction might encourage a search for the appropriate pilot classification, because its use in future experiments could extend the understanding of how other factors affect performance. This would be particularly true in an X-type interaction where the ordering of pilots in terms of performance levels is reversed between levels of a factor.

Other Information

There are certain computations that can be performed to obtain supplementary information with which to interpret the data. F-ratios for a particular effect can be calculated using the percentages given in the analysis-of-variance summary tables. The numerator of the ratio is the percent-variance-accounted-for by an effect divided by its degrees of freedom, and the denominator is the residual percent-variance-accounted-for divided by its degrees of freedom. Significance is indicated at 0.05 and 0.01 levels. A level of 0.01 is considered the appropriate level of significance because it provides some compensation for the multiple tests and measures involved (there is an exception to this in the case of significant pilot by factor interactions as discussed previously).

Statistical significance, by itself, provides little information regarding the operational importance or relative size of an effect. Cohen (20, p. 25-27) suggested, as one guideline, that effect size labels of small, moderate, and large be associated with η^2 values of 1%, 6% and 14% respectively. These values appear reasonable guides for evaluating how much attention should be paid to a statistically significant effect.

The results have been condensed in the interest of keeping reasonable limits on the amount of information presented. The enclosed analysis-of-variance tables summarize the effects of the experimental factors and also present mean differences (high minus low fidelity) between factor levels. Table 3 lists the factor levels in terms of "high" or "low" fidelity levels used to calculate mean differences. In addition, since the approach, hover, and landing task (AHL) and the precision hover task (PHT) were performed separately, and constituted two independent tasks, they will be presented separately.

As expected, pilot differences and pilot-by-factor interactions (combined into a single omnibus term) tended to account for a large portion of the experimental variance. Pilot differences tended to account for the single greatest amount of variance (other than unexplained residual), ranging from 7.0 to 39.7 percent of the total variance across all performance measures. The pilot-by-factor interactions, when combined into a single omnibus term, ranged from 10.0 to 19.0 percent of the variance. Pilot main effects and combined pilot-by-factor interactions are presented in the analysis-of-variance tables.

TABLE 3. EXPERIMENTAL FACTOR LEVELS IN TERMS OF FIDELITY

Factor Levels	LOW	HIGH
Scene Detail	OFT scene	Upgraded VTRS scene
Field of View	OFT	VTRS
Dynamic Seat Cueing	Off	On
Dynamic Inflow	Standard Rotor Model	Updated Aero Model
Seastate	Moderate Seastate (2)	No Seastate
Visual Delay	183 msec	117 msec

Equipment two-factor interactions tended to be small, typically accounting for only a small portion of variance. The six equipment interactions combined generally accounted for less than two percent of the total variance and only a few of these individual interactions were even marginally significant. In the cases where marginal significance was attained (.01-.05), the effects involved were generally of little or no practical importance. For this reason, individual equipment interactions are not presented or discussed, with one exception.

APPROACH, HOVER, AND LANDING TASK

Approach

Analysis-of-variance results for RMS lineup and glideslope error (in feet) and roll angle (in degrees) in the approach segment are shown in Table 4. The equipment factor with the greatest effect on glideslope control was dynamic inflow. Glideslope performance was better with the updated aero model, designed to be more responsive to collective inputs and to primarily facilitate vertical axis control tasks. Scene detail and FOV had significant effects on lineup control and roll activity, with better lineup performance and less roll activity observed with the VTRS FOV and the upgraded VTRS scene. The better lineup performance under the two high level FOV and scene detail options was presumably due to the availability of more visual information from the wider VTRS FOV and enhanced wake in the VTRS scene. The increased roll activity observed with the OFT FOV and OFT scene detail could be associated with the lineup control instability observed with the low level options.

Pilot experience had a highly significant effect on glideslope control. Experienced pilots maintained better glideslope control than did less experienced pilots. Pilot-experience interactions with equipment factors were generally small with one exception. Less experienced pilots tended to maintain lineup better during the approach with the upgraded VTRS scene. Performance was generally poorer under seastate conditions. The relative size of this effect can be seen in Table 4 and subsequent tables.

TABLE 4. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE APPROACH, HOVER, AND LANDING TASK: RMS ERROR SCORES DURING APPROACH SEGMENT

Source of Variance	df	RMS Lineup Error (ft)	RMS GS Error (ft)	RMS Roll Angle (deg)
Dynamic Inflow	1	-0.31[1](0.1)	-0.75(1.3)**	-0.07(0.2)
Dynamic Seat Cueing	1	0.21(0.0)	-0.53(0.6)*	0.01(0.0)
Scene Detail	1	-1.39(1.9)*	-0.08(0.0)	-0.20(2.1)**
Field of View	1	-1.82(3.3)*	-0.61(0.8)	-0.15(1.2)**
Seastate	1	-2.00(4.0)**	-1.01(2.3)*	-0.05(0.2)
Pilot Experience	1	0.86(0.8)	-1.04(2.5)**	0.09(0.5)
Pilot Difference	10	(15.5)**	(25.3)**	(36.2)**
Equipment 2-Factor Interaction	6	(1.4)	(2.0)*	(0.7)
Turbulence X Equipment 2-Factor Int.	4	(0.3)	(0.1)	(0.4)
Pilot Experience X Factor Int.	5	(2.8)*	(1.6)	(0.7)
Other Pilot 2-Factor Int.	50	(12.1)	(15.8)**	(13.3)**
Residual	301	(57.8)	(47.7)	(44.5)

[1] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

Hover

Results for the hover segment are provided in Tables 5 through 7. Lateral and longitudinal errors in this segment were defined as deviations from the center of the rapid securing device (RSD) on the landing pad. Vertical error was defined as deviations from a point 12 feet above the deck. RMS error scores for lateral, longitudinal, and vertical control in the hover are presented in Table 5. Percent time-on-tolerance (TOT) scores for the same measures are presented in Table 6. Two composite percent TOT scores for the three control dimensions combined are presented in Table 7.

There were large FOV effects on RMS error and percent TOT for lateral and longitudinal control in the hover. Hover performance was substantially better with the VTRS FOV compared to the OFT FOV in both lateral and longitudinal control (Tables 5 and 6). There was no significant FOV effect on vertical control in the hover. However, there was a significant FOV by pilot interaction on RMS error and percent TOT for altitude control in the hover. As previously discussed, an effect involving a significant pilot interaction may not be significant whereas a smaller effect not involving a significant pilot interaction may be significant. This is the case here since the FOV main effect had to be tested against the interaction rather than the pooled residual term (Tables 5 and 6). Nevertheless, the composite TOT scores in Table 7 show a substantial difference in overall hover performance in favor of the VTRS FOV.

Dynamic inflow also affected performance in the hover segment. Vertical control during hover was better with the updated aero model than with the standard rotor model (Tables 5 and 6). Again, if a dynamic inflow effect was to occur in the hover segment, it was expected in the vertical dimension where the updated aero model was designed to aid control. There was a statistically significant dynamic seat cueing effect on vertical RMS error, although it accounted for less than one percent of the variance. TOT scores in the vertical dimension were not affected by the g-seat manipulation. There were no significant scene detail effects on any of the hover performance measures.

Pilot experience effects were inconsistent. The more experienced pilots demonstrated better lateral control in the hover (in terms of both RMS error and TOT scores) than the less experienced pilots, but the less experienced pilots demonstrated significantly better altitude control as measured by TOT (Table 6). This reversal is puzzling but could result from control biases on the part of the more experienced pilots. Pilot experience interactions with equipment factors were small. Equipment two-factor interactions were not particularly informative and when combined into a single omnibus term, tended to account for little of the experimental variance. The only equipment interaction of any interest in the hover segment was scene detail by FOV for altitude control. Altitude control was best with the upgraded VTRS scene and VTRS FOV, but much poorer with the VTRS scene and OFT FOV. There were no differences in performance with the OFT scene under either FOV condition.

TABLE 5. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE APPROACH, HOVER, AND LANDING TASK: RMS ERROR SCORES DURING HOVER SEGMENT

Source of Variance	df	RMS Error R/R[1] Longitudinal	Lateral	RMS Error Vertical
Dynamic Inflow	1	0.15[2](0.1)	-0.05(0.0)	-0.28(2.1)**
Dynamic Seat Cueing	1	-0.27(0.2)	-0.05(0.0)	-0.18(0.8)*
Scene Detail	1	0.61(1.2)	-0.17(0.5)	-0.01(0.0)
Field of View	1	-2.17(14.9)**	-0.69(7.6)**	-0.26(1.7)
Seastate	1	-1.29(5.4)**	-1.04(17.5)**	-0.43(4.4)**
Pilot Experience	1	-0.36(0.3)	-0.34(1.8)**	0.13(0.4)
Pilot Difference	10	(8.0)**	(13.0)**	(29.4)**
Equipment 2-Factor Interaction	6	(1.1)	(0.4)	(1.8)*
Turbulence X Equipment 2-Factor Int.	4	(0.6)	(0.7)	(0.9)
Pilot Experience X Factor Int.	5	(1.6)	(0.3)	(0.7)
Other Pilot 2-Factor Int.	50	(14.4)**	(13.8)**	(17.5)**
Residual	301	(52.2)	(44.4)	(40.3)

[1] R/R = Relative to the Rapid Securing Device (RSD)
[2] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

TABLE 6. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE APPROACH, HOVER, AND LANDING TASK: TIME-ON-TOLERANCE SCORES DURING HOVER SEGMENT

Source of Variance	df	TOT +5,-3 ft Longitudinal	TOT ±2 ft Lateral	TOT ±2 ft Vertical
Dynamic Inflow	1	-1.97[1](0.1)	1.36(0.1)	6.05(1.0)**
Dynamic Seat Cueing	1	1.14(0.0)	0.20(0.0)	3.48(0.3)
Scene Detail	1	-5.56(0.8)	3.95(0.5)	0.19(0.0)
Field of View	1	23.60(13.2)**	17.63(9.9)**	8.43(1.9)
Seastate	1	16.32(6.5)**	19.91(12.8)**	10.06(2.8)**
Pilot Experience	1	2.30(0.1)	5.86(1.1)*	-9.90(2.7)**
Pilot Difference	10	(10.3)**	(11.6)**	(29.2)**
Equipment 2-Factor Interaction	6	(0.9)	(0.5)	(2.2)*
Turbulence X Equipment 2-Factor Int.	4	(0.3)	(1.3)	(0.7)
Pilot Experience X Factor Int.	5	(1.3)	(0.8)	(0.6)
Other Pilot 2-Factor Int.	50	(15.1)**	(18.3)**	(18.1)**
Residual	301	(51.4)	(43.1)	(40.5)

[1] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

TABLE 7. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE APPROACH, HOVER, AND LANDING TASK: COMPOSITE TIME-ON-TOLERANCE SCORES DURING HOVER SEGMENT

Source of Variance	df	Composite X+Y+Z[1]	Composite X+Y+Z[2]
Dynamic Inflow	1	0.09[3](0.0)	2.95(0.5)
Dynamic Seat Cueing	1	0.75(0.0)	0.70(0.0)
Scene Detail	1	-2.14(0.1)	-0.97(0.1)
Field of View	1	23.51(14.9)**	13.08(8.5)**
Seastate	1	23.01(14.6)**	15.29(12.0)**
Pilot Experience	1	5.65(0.9)*	2.01(0.2)
Pilot Difference	10	(7.7)**	(10.4)**
Equipment 2-Factor Interaction	6	(0.8)	(0.5)
Turbulence X Equipment 2-Factor Interaction	4	(0.5)	(1.7)*
Pilot Experience X Factor Interaction	5	(1.0)	(1.0)
Other Pilot 2-Factor Interaction	50	(13.6)**	(16.9)**
Residual	301	(45.9)	(48.2)

[1]X (longitudinal) = ± 5 ft; Y (lateral) = ± 3 ft; Z (vertical) = ± 3 ft
[2]X (longitudinal)= + 5 ft - 3 ft; Y (lateral) = ± 2 ft; Z (vertical) = ± 2 ft
[3]Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

Landing

Analysis-of-variance summaries for touchdown quality measures are provided in Table 8. Longitudinal positioning, defined in terms of fore/aft deviation from the prescribed touchdown point was significantly better with the VTRS FOV (Table 8). The effect of FOV on vertical velocity at touchdown was also statistically significant with harder touchdowns under the OFT FOV. No simulator equipment factor affected touchdown accuracy in the lateral dimension.

There was a significant effect on longitudinal positioning and vertical velocity at touchdown as a result of the seastate manipulation. Pilots tended to land harder under rough seas, and had difficulty with placement in the longitudinal dimension in landing. Seastate-by-equipment interactions would be of particular interest in this context since an equipment factor that improved performance under high seastate conditions would be of interest in training. There were, however, no significant seastate-by-equipment interactions.

There was a significant effect on the lateral dimension of touchdown due to pilot experience. The more experienced pilots demonstrated more precise lateral positioning than their less experienced counterparts. A significant pilot experience by FOV interaction was also observed. High-experience pilots performed better on longitudinal positioning at touchdown with the VTRS FOV, but experienced more difficulty in longitudinal positioning with the OFT FOV. The omnibus equipment two-factor interaction term was significant at the .01 level for absolute longitudinal error. Examination of the individual interactions revealed that the dynamic seat cueing by FOV interaction was the largest contributor to this effect. This result indicated that performance was poorest with the OFT FOV and no seat cueing, and that performance was best with the VTRS FOV and no seat cueing. This result lends support to the notion that dynamic seat cueing can improve performance under narrow (or inadequate) FOV conditions, but becomes redundant under wide field-of-view conditions.

PRECISION HOVER TASK

Results for the precision hover task are presented in Tables 9 through 11. RMS error scores for longitudinal and lateral control relative to the RSD in the hover, and RMS error for altitude control in the hover are presented in Table 9. Composite TOT scores for longitudinal, lateral and vertical control in the hover, within two tolerance bands, are presented in Table 10. Table 11 provides summaries for two other measures, RMS roll error and RMS pitch error in the hover. Analysis-of-variance summaries for TOT (as described in Table 6) for each individual control dimension (lateral, longitudinal, and vertical) in the hover, paralleled the RMS error results (Table 9). These results are not presented as they are essentially identical to those given in Table 9.

There were highly significant effects on all performance measures (Tables 9 and 10) due to the FOV manipulation. Hover performance, measured in terms of RMS error for the lateral, longitudinal, and vertical axes, and the composite TOT scores, were significantly more precise with the VTRS FOV than with the OFT FOV. In fact, FOV accounted for almost 20% of the total variance in the RMS error data for the longitudinal and lateral dimensions of the hover (Table 9) and 30% of the variance in the composite TOT measures (Table 10).

TABLE 8. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE APPROACH, HOVER, AND LANDING TASK: TOUCHDOWN MEASURES

Source of Variance	df	Absolute Error Longitudinal	Absolute Error Lateral	Vertical Velocity
Dynamic Inflow	1	-0.04[1] (0.0)	-0.17(0.6)	0.02(0.0)
Dynamic Seat Cueing	1	-0.08(0.1)	-0.07(0.1)	-0.26(0.3)
Scene Detail	1	0.18(0.4)	-0.01(0.0)	-0.44(0.7)
Field of View	1	-0.42(2.3)**	-0.27(1.4)	-0.45(0.8)*
Seastate	1	-0.30(1.2)**	-0.15(0.5)	-0.58(1.3)**
Pilot Experience	1	0.17(0.4)	-0.48(4.6)**	0.40(0.6)
Pilot Difference	10	(7.8)**	(7.0)**	(19.2)**
Equipment 2-Factor Interaction	6	(3.8)**	(1.4)	(1.6)
Turbulence X Equipment 2-Factor Int.	4	(1.0)	(0.8)	(1.1)
Pilot Experience X Factor Int.	5	(3.2)*	(0.7)	(0.3)
Other Pilot 2-Factor Int.	50	(14.4)	(19.0)**	(16.2)**
Residual	301	(65.4)	(63.9)	(57.9)

[1] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

TABLE 9. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE PRECISION HOVER TASK: RMS ERROR SCORES DURING HOVER SEGMENT

Source of Variance	df	RMS Error R/R[1] Longitudinal	RMS Error R/R[1] Lateral	RMS Error Vertical
Dynamic Inflow	1	0.50[2](1.4)**	-0.12(0.3)	0.07(0.2)
Dynamic Seat Cueing	1	0.39(0.8)*	0.10(0.3)	0.07(0.2)
Scene Detail	1	-0.31(0.6)	-0.04(0.1)	-0.03(0.1)
Field of View	1	-2.08(19.4)**	-0.86(19.1)**	-0.40(4.6)*
Visual Delay	1	-0.38(0.7)*	0.02(0.0)	-0.15(0.7)*
Pilot Experience	1	1.42(9.4)**	0.08(0.2)	0.54(9.1)**
Pilot Difference	10	(14.6)**	(23.9)**	(30.9)**
Equipment 2-Factor Interaction	10	(2.3)*	(1.4)	(0.9)
Pilot Experience X Factor Int.	5	(1.8)**	(2.5)**	(0.0)
Other Pilot 2-Factor Int.	50	(14.1)**	(18.3)**	(12.6)**
Residual	297	(34.9)	(33.9)	(40.7)

[1] R/R = Relative to the Rapid Securing Device
[2] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

TABLE 10. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE PRECISION HOVER TASK: COMPOSITE TIME-ON-TOLERANCE SCORES DURING HOVER SEGMENT

Source of Variance	df	Composite X+Y+Z[1]	Composite X+Y+Z[2]
Dynamic Inflow	1	-3.16[3](0.4)	-0.41(0.0)
Dynamic Seat Cueing	1	-6.02(1.3)**	-1.43(0.3)
Scene Detail	1	2.54(0.2)	-0.26(0.0)
Field of View	1	32.83(33.5)**	17.82(29.2)**
Visual Delay	1	1.66(0.1)	2.29(0.5)
Pilot Experience	1	-10.34(3.6)**	-6.84(4.5)**
Pilot Difference	10	(11.0)**	(11.4)**
Equipment 2-Factor Interaction	10	(1.5)	(1.9)
Pilot Experience X Factor Interaction	5	(1.6)*	(0.5)
Other Pilot 2-Factor Int.	50	(11.5)**	(12.8)**
Residual	297	(35.3)	(38.9)

[1]X (longitudinal) = ± 5 ft; Y (lateral) = ± 3 ft; Z (vertical) = ± 3 ft
[2]X (longitudinal)= + 5 ft - 3 ft; Y (lateral) = ± 2 ft; Z (vertical) = ± 2 ft
[3]Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

TABLE 11. ANALYSIS-OF-VARIANCE SUMMARIES FOR THE PRECISION HOVER TASK: AIRCRAFT CONTROL MEASURES DURING HOVER SEGMENT

Source of Variance	df	RMS Roll Angle (deg)	RMS Pitch Angle (deg)
Dynamic Inflow	1	-0.018[1](0.2)	0.014(0.1)
Dynamic Seat Cueing	1	0.025(0.5)	-0.011(0.0)
Scene Detail	1	-0.027(0.6)	-0.068(1.5)*
Field of View	1	0.008(0.0)	0.012(0.0)
Visual Delay	1	-0.042(1.3)*	-0.015(0.1)
Pilot Experience	1	0.03(0.7)	0.20(11.6)**
Pilot Difference	10	(31.1)**	(39.7)**
Equipment 2-Factor Interaction	10	(1.2)	(1.4)
Pilot Experience X Factor Interaction	5	(0.9)	(0.6)
Other Pilot 2-Factor Int.	50	(16.3)**	(10.0)**
Residual	297	(47.2)	(35.2)

[1] Mean difference, i.e., mean for high level condition minus low level condition. (Values of eta-squared in parentheses)

*$p < .05$
**$p < .01$

The visual delay manipulation resulted in marginally significant effects on longitudinal and vertical control in the hover. In both cases, performance was better with the shorter delay of 117 msec (Table 9). There was also a significant increase in roll activity in the hover with the longer delay of 183 msec (Table 11). Overall, the effects for visual lag were small but consistently favored the shorter lag (117 msec). The dynamic seat cueing factor had a marginally significant effect on longitudinal control in the hover (Table 9) and in composite TOT performance in the larger tolerance band (Table 10). In both cases however, performance was poorer when g-seat cueing was available.

There were marginally significant scene detail and dynamic inflow effects in the precision hover task. Although pitch control was significantlly improved with the VTRS scene (Table 11), there were no other performance differences attributed to this factor. Dynamic inflow did not affect vertical control in the hover, although it did significantly affect longitudinal control with better control observed under the standard rotor model condition (Table 9).

Several significant effects on hover performance were due to pilot experience. The less experienced pilots performed better than the more experienced pilots on all measures of performance during the hover (Tables 9 through 11). The consistency of this effect may indicate the presence of a performance "bias" on the part of the more experienced pilots. That is, as a result of their more extensive shipboard landing experience, the more experienced pilots may have adopted unique control strategies which carried over into this experiment.

During the hover phase of the precision hover task, three separate vertical gust disturbances (counterbalanced combinations of up and down) were introduced to assess the effects of the experimental factors on hover stability. An analysis of reaction times in response to the gust disturbances indicated a highly significant effect for dynamic inflow (Table 12). On the average, pilots responded to the gust disturbances 97.3 msec faster when dynamic inflow was available compared to when it was not. No other significant equipment factors effects were observed for this measure, although a highly significant pilot-differences effect indicated wide variability between individual pilots' average reaction times.

Power spectral density techniques were also used to compare the frequency content of pilot stick inputs under the various experimental conditions. This work is incomplete at this time, although preliminary analyses indicated that there were no significant differences in the frequency content of cyclic movement between the two visual delay conditions. Work is continuing in this area of performance measurement.

PILOT OPINION

Pilots were asked to rate both levels of each simulator design feature in terms of simulation fidelity, adequacy for training, and adequacy for skill retention. A five-point rating scale (where 1 = "very poor" and 5 = "very good") was used. A rating of the effect of the difference between factor levels on performance of each of the two tasks was also obtained using a four-point rating scale (where 1 = "no perceived effect of the difference on performance" and 4 = "large perceived effect of the difference on performance"). This was done for each task (Table 13). In addition, pilots were asked to provide brief, written comments concerning the design options.

TABLE 12. REACTION TIME TO GUST INPUTS FOR THE PRECISION HOVER TASK

Source	df	Time (msec)
Dynamic Inflow	1	-97.3[1](3.8)**
Dynamic Seat Cueing	1	-21.3(0.0)
Scene Detail	1	8.3(0.0)
Field of View	1	16.3(0.0)
Visual Delay	1	-21.7(0.0)
Pilot Experience	1	24.7(0.2)
Pilot Differences	10	(2.8)**
Equipment 2-Factor Interactions	10	(3.2)
Pilot Experience x Factor Interaction	5	(0.7)
Other Pilot 2-Factor Interactions	50	(7.5)
Residual	297	(81.5)

[1] Mean difference, i.e., mean for high level conditions minus low level conditions. (Values of eta-squared in parentheses.)

* $p < .05$
** $p < .01$

TABLE 13. PILOT RATINGS OF THE EXPERIMENTAL FACTORS

Approach, Hover, and Landing Task

Factor	Option	Fidelity*	Adequacy* for Training	Adequacy* for skill Retention	Estimated** Effect Size
Field of View	VTRS	4.33	4.25	4.33	3.67
	OFT	1.83	1.58	2.16	
Scene Detail	VTRS	3.20	2.90	3.70	2.45
	OFT	1.90	2.40	2.70	
Dynamic Seat	On	2.25	2.33	2.50	2.33
	Off	2.83	2.83	3.17	
Dynamic Inflow	On	3.18	2.91	3.00	3.00
	Off	2.90	2.90	3.00	
Seastate	On	3.82	3.91	4.17	3.18
	Off	3.18	3.27	3.18	

Precision Hover Task

Factor	Option	Fidelity	Adequacy for Training	Adequacy for skill Retention	Estimated Effect Size
Field of View	VTRS	4.33	4.25	4.33	3.67
	OFT	1.67	1.58	2.17	
Scene Detail	VTRS	3.60	3.60	3.80	2.09
	OFT	2.40	2.60	3.10	
Dynamic Seat	On	2.17	2.24	2.58	2.50
	Off	2.67	2.75	3.00	
Dynamic Inflow	On	3.00	3.09	3.18	3.18
	Off	2.90	2.90	3.30	
Visual Delay	117	3.50	3.92	3.83	2.83
	183	2.17	2.33	2.42	

* Five-point rating scale where 1 = "very poor" and 5 = "very good."
** Four-point categorical rating where 1 = "none," 2 = "small," 3 = "moderate," and 4 = "large."

As indicated in Table 13, pilots showed a marked preference for the wide (VTRS) field of view over the smaller (OFT) field of view across all measures for both tasks. Differences between the two field-of-view conditions also had the largest perceived effect on performance in both tasks. The more detailed VTRS scene was judged to be superior to the less detailed OFT scene for both tasks in general, but differences between the two scene detail conditions were perceived by the pilots as having comparatively small effects on performance.

In both tasks, the presence of dynamic seat cueing was not rated as highly as the absence of cueing. The size of the perceived effect of the difference between the two levels of this factor was comparatively small. Ratings for the dynamic inflow did not show a pronounced preference for one level or the other. In the precision hover task, the shorter (117 msec) visual delay condition was rated higher across all measures than the longer delay (183 msec). The perceived effect of the differences between the delay conditions tended toward moderate.

Pilots' written comments concerning field of view indicated that the larger (VTRS) field of view was preferred because of the greater ease with which visual information essential to task performance could be obtained. Pilots generally stated that the smaller (OFT) field of view made the pickup of visual information unrealistically difficult. Features of the ship used to maintain position in the hover and to guide placement in the landing (such as fore/aft lineup lines, hangar railing, etc.) were often obscured with the smaller field of view.

With regard to scene detail, several pilots commented that aircraft movements around the deck were perceived somewhat faster with the more highly detailed scene. Several pilots reported minor difficulties in positioning the aircraft in the low detail condition. Approximately half of the pilots did not think that differences between the high and low detail scenes affected performance.

Several pilots indicated that they perceived a difference between the two dynamic inflow conditions, specifically in the manner in which the aircraft responded to collective inputs. However, pilots generally indicated that they could not tell whether the dynamic inflow was "on" or "off," and several pilots showed a tendency to confuse dynamic inflow with visual delay. Pilots' opinions regarding the utility of the dynamic seat cueing were generally negative. Several indicated that the g-seat provided a "mild" sensation of vertical motion. One pilot commented that under nonturbulent conditions the g-seat had a realistic feel, but under turbulent conditions it felt unrealistic. Pilots also indicated that the seat did not provide cues appropriate to hard or angled landings.

Several pilots stated that the 183 msec transport delay led to a tendency to over-control the aircraft. One pilot commented that with long visual delays it is possible to learn to "fly the simulator," but that poor transfer to the actual flight environment might occur. Pilots generally felt that the simulation of moderate seastate conditions provided a useful representation of conditions encountered in actual flight. Most pilots agreed that the training value of simulated seastate conditions was likely to be great.

DISCUSSION

In simulation research, individual differences tend to account for much of the variance in the data (4). In this experiment, pilot differences tended to account for a large portion of variance. Pilot-by-factor interactions, combined into a single omnibus term, also accounted for a substantial portion of the variance. Although pilots were differentiated in the experiment on the basis of their flight experience, subject differences and subject-by-factor interactions within experience level were still large, and were viewed as unexplained variance. Thus, research into covariates and other pilot classifications need to be a continuing concern.

Nevertheless, this experiment was successful in the development and validation of a performance measurement package and experimental procedures for subsequent helicopter shipboard landing experiments. In addition, the results provide some valuable insight into simulator design issues for training helicopter landing on small ships. The discussion that follows will emphasize factor main effects and discuss relevant pilot experience by factor interactions and equipment interactions as appropriate.

EQUIPMENT FACTORS

Field of View

Field of view was, by far, the most important of the equipment factors in terms of its effects on performance for both tasks. Pilot performance was significantly better in all phases of the approach, hover and landing task, and in the precision hover task under the VTRS FOV. The enhanced simulator performance of both tasks under the wider VTRS FOV was especially apparent in the hover segment where the lower portion of the FOV is most critical. The better performance under the VTRS FOV was likely a result of acquiring more visual information from the lower portion of the forward and side windows. In addition, pilot opinion was strongly in favor of the VTRS FOV.

In contrast, Westra and Lintern (9) also tested the smaller OFT FOV versus the wider VTRS FOV, but found only minor effects on performance. However, there were some notable differences between the present experiment and Westra and Lintern's (9) experiment. First, and most important, in the latter experiment the simulated OFT FOV was estimated from design specifications. The values used in the present research effort were based on measurements of the actual field of view taken in the OFT by VTRS staff engineers. These actual measurements differed substantially from the design values used by Westra and Lintern (9). The vertical field of view was 16 degrees less and the horizontal field of view was 15 degrees less. Most critically, the downward field of view was nine degrees less in the OFT than the stated design values. In addition, the Westra and Lintern (9) experiment did not include the gaps in the visual scene between the display monitors (compare Fig.'s 1 and 4)

Second, as previously noted, there were procedural problems in the Westra and Lintern (9) experiment that resulted in less than optimal measurement during the hover segment. In the present experiment, the hover segment was specifically defined in both tasks, and the experimental procedures and performance measurement package were further developed and validated. This resulted in more sensitive measurement with more power to detect differences in pilot performance. Thus, there is some difficulty in comparing the results of the two research efforts because of changes in procedure. However, it appears that the differences in results for field of view between the two research efforts are primarily due to the difference between the OFT preliminary design values and the actual FOV in the OFT.

Scene Detail

The strongest effects as a result of scene detail were in the approach phase of the approach, hover, and landing task. Performance in terms of tracking the extended centerline of the ship during the approach was better with the upgraded VTRS scene. It appears that the enhanced depiction of the ship's wake in the upgraded VTRS scene provided more information of the type that would enable detection of lineup, and aid the ambient processes that support orientation in the approach (e.g. optical flow rate). There were no other significant effects as a result of scene detail in the approach, hover, and landing task.

In contrast, scene detail emerged as the most important experimental factor in Westra and Lintern's (9) experiment in terms of its effect on pilots' performance throughout all task segments of the approach, hover, and landing task. However, their scene detail manipulation involved a ship that only depicted an outline of the deck and hangar versus a ship with full deck and hangar markings, ship's wake, and seascape pattern. The scene detail manipulation in the present experiment was much more subtle. In the current experiment, the OFT scene had a ship with deck and hangar wall markings, a wake, and other features, while the upgraded VTRS scene included all the features of the OFT scene along with additional masts, simulated pad eyes and RSD tracks on the deck, and an enhanced wake. The differences between the two scenes were not large, and from the pilot opinion questionnaire, were not readily apparent to many of the pilots.

There were also no significant performance effects as a result of scene detail for the precision hover task. In terms of the task, as the pilots move over the deck and into the hover, their attention is largely directed towards acquiring visual information from the surface of the ship's hangar wall and deck. The results indicate that the additional markings in the upgraded VTRS scene (essentially the pad eyes and RSD tracks) did not provide any additional information to improve hover performance. Thus, the current deck and hangar wall markings in the OFT scene are adequate from a hover performance viewpoint.

Nevertheless, it is apparent from the better lineup performance during the approach in the approach, hover, and landing task, with the upgraded VTRS scene, that a specific cue (the enhanced wake) can provide considerably more position and orientation information to the pilot. Other less specific sources of optical information may also be important in the guidance of aerial self-motion. The nature and amount of environmental surface texture (e.g., seascape detail) has been demonstrated to have an effect on sensitivity to visually specified self-motion (11). A display containing very few perceivable optical discontinuities (contrast boundaries or "edges") may be too visually "sparse" to support adequate control of self-motion, while a display with too many discontinuities may be equally ineffective. Detection of loss in altitude (11), and loss in forward speed (21) in flight simulation, has been shown to be less accurate when the "density" of optical texture is either very high or very low. These findings from self-motion research parallel normal contrast sensitivity functions (12,22) which indicate that peak sensitivity to grating patterns exists in the mid-range of spatial frequencies and diminishes with increased or decreased spatial frequency.

In summary, it is particularly difficult to determine how much and what visual information is critical in any flight task (23). With better lineup performance with the upgraded VTRS scene, presumably due to the enhanced wake, other strategically placed and/or designed features could also improve performance in other segments of the approach, hover, and landing task. Perhaps a ladder on the hangar wall, or a figure on the deck to provide additional size constancy information to the pilots, would be useful. Thus, the investigation of scene detail issues needs to be a continuing concern.

Dynamic Seat Cueing

There were some small effects on vertical control in favor of the dynamic seat cueing during the approach and hover segments of the approach, hover and landing task. These results essentially paralleled those of Ricard and Parrish (24) who also found a very small but positive g-seat effect for a precision hover task. These results are encouraging, particularly since the developmental work following the Westra and Lintern (9) experiment was concentrated in the vertical dimension. However, results for the precision hover task showed no positive g-seat effect. In fact, the g-seat appeared to have a detrimental effect on some hover performance measures. The precision hover task was more demanding, in some respects, than the hover portion of the approach, hover, and landing. This was due to the vertical wind gusts which were of substantial force. However, in this environment, positive g-seat effects should have been more apparent. Wind gusts were added to the task, in part, to aid in documenting g-seat effects.

Pilots also had mixed feelings on the usefulness of the dynamic seat cueing. They tended to rate the operational g-seat as inadequate in terms of fidelity and training for novice pilots. Although this suggests there may still be fundamental problems with the implementation of dynamic seat cueing, it may also be the case that the wide angle visual display is so compelling that motion seat cueing is at best redundant, and may be somewhat negative since it stimulates the g-effects but cannot duplicate them. This idea is supported by one result which showed a positive benefit for dynamic seat cueing under the narrow field-of-view condition, but no effect under the wide field-of-view condition for the landing phase of the approach, hover, and landing task.

Pilot response technique when reacting to vertical gusts was generally a deliberate and methodical displacement of the collective to counter the gust. It appeared that, although speed was necessary, the estimate of required final magnitude was generated during the gust in a "ramp" motion and visual cues for this information were not enhanced by the seat cues. The question of whether motion platform cueing would improve the simulation for this task was not addressed. While motion seat haptic cueing and motion platform vestibular cueing are related, they do provide certain motion cues in fundamentally different ways.

Visual Transport Delay

This factor had some small but consistent effects on objective performance measures and aircraft control. Westra and Lintern (9) also found visual delay effects when they compared 217 msec to 117 msec. In that experiment, there were touchdown effects in favor of the shorter delay and pilot opinion of the long delay was quite negative. In the present experiment comparing 183 msec to 117 msec, there were no touchdown effects (hover effects only), and pilot opinion, although still negative, was not quite so strongly negative. It would appear then that the 217 msec delay is more disruptive of performance than 183 msec. A delay of 183 msec, while not necessarily desirable, appears "flyable" with only minor effects on performance compared to 117 msec. Pilot opinion, however, indicates that 183 msec delay is inadequate for training novice pilots (see Table 13).

Although the 183 msec condition appears "flyable", there are several issues which bear consideration. First, subjects can typically compensate for lags (adjust their control strategy) if they can anticipate the course (25). This suggests that pilots will be able to "fly" even poor simulations with excessively long visual delays quite well given sufficient practice time. For example, Uliano, Lambert, Kennedy, and Sheppard (26) investigated the effect of visual delay and delay variability on simulator sickness for helicopter air taxi and slalom maneuvers. They found that a delay of 215 $\pm$ 70 msec did not contribute to simulator sickness and was still "flyable" (although neither desirable nor recommended). To the extent that pilots can adjust to the simulation, results for task outcome measures could show little or no difference, but pilots may have adjusted their control strategy in a major way to achieve this. If this has occurred, there would be an implication for transfer-of-training. Transfer could be negative if pilots transferred adjusted strategies to the aircraft. This concern is a legitimate one, but can be investigated by examining the control activity of the pilot. In this experiment, both response time to gust inputs (Table 12) and the control frequency response of the pilots under the different experimental conditions were examined. At this time, no evidence was found of any meaningful difference in control behavior between the 183 and 117 msec delay conditions. However, it should be noted that frequency domain analyses for the collective response has not been completed at this time.

Another consideration is the matter of absolute lag versus a lag difference. Results suggest that adding 66 msec to an existing 117 msec does not materially affect performance. However, any amount of visual transport delay is a departure from perfect reality. The ultimate issue is the question of how the absolute lag in a simulator affects transfer to the operational task. There is some information available which can be brought to bear on this issue. At VTRS, the shortest visual delay that can be obtained is 117 msec, and there is information on performance effects when the lag is increased by 66 msec (two frames) and 100 msec (three frames). Ricard et al., (13) conducted an experiment for a precision hover task in which they compared a 128 msec visual delay to a 66 msec delay (two frames) at the NASA Langley research facility. They found that this difference resulted in a performance decrement for RMS error in the hover which accounted for approximately 1.3 percent of the variance in the hover. Their results closely approximate those for the present two-frame difference. From this it can be inferred that the difference between a 66 msec visual delay and no visual delay would be approximately the same magnitude.

It appears that 66 msec (two frames) of delay is a just noticeable difference (JND) in terms of both performance effects, which can be statistically documented, and pilot perception. It can be inferred from the available information that 33 msec (one frame) is less than a JND. Therefore, adding 33 msec to an acceptable absolute lag would not affect the simulation in a noticeable way. But what is an acceptable absolute lag? Data from two field transfer experiments (27,28) indicate positive transfer from the simulator to operational tasks with a delay of 117 msec. From this it appears that a delay of 117 msec is acceptable. However, these results were for the aircraft carrier landing and air-to-ground bombing tasks which demand considerably different control-response activity.

A lag of 183 msec is marginally acceptable for the SH-60B OFT from a performance viewpoint. However, it must be pointed out that pilots rated this delay as inadequate for training novice pilots. Also, although performance effects are small, we have the data in hand to make the case that "shorter is better", down to 66 msec.

Dynamic Inflow

There were significant performance benefits as a result of dynamic inflow during the approach, hover, and landing task. Essentially, the measures affected by the updated aero model were those in the vertical dimension (glideslope control in the approach and altitude control in the hover) of the task. Since the updated aero model was designed to produce a more accurate representation of the vertical responses of the helicopter produced by collective inputs, it is concluded that the updated software performed as designed and resulted in a meaningful improvement in performance.

The results for the precision hover task were less well defined. Although time series analyses revealed faster response time to wind gusts with the updated aero model, other objective performance measures did not reveal any positive benefit of the updated aero model. The precision hover with wind gusts imposed considerably different demands on the pilots than the hover portion (without wind gusts) of the approach, hover, and landing task. These differences apparently account for differing results between the two tasks for dynamic inflow (this also applies to a lesser degree for dynamic seat cueing results). In addition to differences required of pilot response, the precision hover task (with wind gusts) was more difficult and resulted in greater performance variability. In the presence of greater variability, effects that are fairly small or subtle are harder to statistically detect, and this may in part explain the difference in results for the two tasks.

RECOMMENDATIONS

The research effort reported here, along with the Westra and Lintern (9) effort, comprises the performance phase of research on simulator design and instructional features for the helicopter shipboard landing task. The next phase of this research effort will be an in-simulator transfer of training experiment in which pilots novice to the task will be trained under various simulator and instructional conditions, and then tested under a high fidelity simulator configuration. It is in this phase that transfer-of-training issues rather than performance alone will be initially addressed. Under this framework, recommendations that result from the performance research phase bear directly on experimental design for transfer-of-training experiments. However, in the case of a recommendation to not include a factor in the next research phase, there is a direct implication for simulator design. The implications then need to be considered in terms of existing operational simulators, acquisitions and cost, and based on this, final recommendations can be made. The following recommendations are based on results from the performance phase of the helicopter shipboard landing research and take into account the issues discussed above.

Field of View

Both objective measures and pilot opinion indicate that a wide FOV is important. It appears that the FOV similar to that currently in use with the SH-60B OFT is inadequate, whereas the VTRS FOV appears to be adequate for training the helicopter shipboard landing task. There is a high probability that an intermediate level of FOV (between the VTRS and OFT) would be sufficient for training the task. Since the helicopter training community is considering intermediate fields of view, it is recommended that an intermediate field of view be evaluated in the next phase of research (in-simulator transfer-of-training) for the helicopter shipboard landing task.

Dynamic Seat Cueing

The results indicated that dynamic seat cueing did not meaningfully improve performance. Although there were some very small effects in favor of the g-seat in the approach, hover, and landing task, the performance benefits were minor. In addition, dynamic seat cueing actually appeared to have a detrimental effect on some performance measures in the precision hover task. Pilots also had mixed feelings on the usefulness of the g-seat and generally rated it as inadequate for the task. Thus, further research on g-seat cueing at VTRS for the helicopter shipboard landing task is not recommended, and g-seat cueing as implemented at VTRS is not recommended for helicopter flight simulation. The seat shaker, however, appeared to work very successfully in reproducing seat vibration and is recommended for helicopter trainers.

Scene Detail

There were some small effects in the approach phase as a result of the scene detail manipulation in favor of the upgraded VTRS scene. In addition, less experienced pilots tended to benefit more from the upgraded VTRS scene in the approach than with the simulated OFT scene. It appeared that the enhanced wake provided more information of the type needed to support lineup control during the approach. Although pilot opinion was generally in favor of the VTRS scene, there were no other objective performance benefits with the upgraded VTRS scene. Because of the small effects, the continued study of this issue in the transfer-of-training research phase is not recommended. The use of the upgraded scene is recommended as a constant condition for future VTRS research.

Visual Transport Delay

The issue of visual delay in helicopter flight simulation was discussed extensively earlier, and was defined as the transport delay between stick input and visual output. Based on our results, and summarizing the discussion, we stated that a lag of 183 msec was marginally acceptable for this task. Visual transport delays longer than 183 msec are not recommended, and visual systems in current operation with delays longer than 183 msec should be upgraded. A constant condition of 117 msec is recommended for future VTRS transfer-of-training research. The small effects seen on performance do not warrant inclusion of this factor in an in-simulator transfer-of-training experiment.

Dynamic Inflow

There were some small to moderate performance benefits in the approach, hover, and landing task as a result of the updated dynamic inflow software. The updated aero model appeared to work as it was designed and offered a genuine performance benefit. Thus, it is recommended that the updated software be incorporated as a standard feature at VTRS and in other helicopter simulators whose aerodynamic models are adaptable to dynamic inflow. Further investigation (nonexperimental) is needed on optimal modeling of rotor transient response characteristics.

Seastate

Seastate was included in the present experiment to manipulate task difficulty. As such, it was used to examine the effects of equipment factors under different levels of difficulty. Although no interactions of significance emerged, the seastate model appeared to serve its purpose well. The seastate model was well accepted by pilots and can be used for training purposes. Since this is a training issue (if and when to introduce it), this factor should be included in the in-simulator transfer-of-training experiment.

SUMMARY

Tables 14 and 15 summarize the experimental feature effects for the approach, hover, and landing task, and the precision hover task, respectively. There were large effects due to field-of-view in all task segments for both tasks, with better performance under the wider VTRS FOV. There were some small effects as a result of scene detail in the approach phase, with better performance under the upgraded VTRS scene. There were no other meaningful performance benefits resulting from scene detail for either task. There were moderate to small effects due to dynamic inflow in vertical control dimensions in the approach, hover, and landing task, with better performance under the updated aero model. The dynamic seat cueing did not result in any meaningful performance effects in either task. There were some small effects as a result of visual delay in the precision hover task, with better performance under the shorter delay.

TABLE 14. 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 FOV
Dynamic Inflow	Moderate/ Small	Effects in glideslope during the approach and altitude control during hover	Updated Aero Model
Scene Detail	Small	Effects in lineup and roll activity in the approach segment	Upgraded VTRS Scene
Dynamic Seat	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

*Option resulting in better simulator performance. In cases where quality measures were not affected, no determination of "better" was possible.

TABLE 15. SUMMARY OF EFFECTS FOR THE PRECISION HOVER TASK

Factor	Effect Size	Segment/Measurement	Better Option*
Field of View	Large	Effects across many measures	VTRS wide FOV
Scene Detail	Small	Effected pitch control in hover	?
Dynamic Inflow	Small	Improved response to wind gusts	Updated Aero model
Visual Delay	Small	Effected longitudinal and vertical positioning and roll activity in hover	117 msec
Dynamic Seat	Small	No meaningful performance benefits with g-seat on	?
Pilot Differences	Large	Large control differences	n/a

*Option resulting in better simulator performance. In cases where quality measures were not affected, no determination of "better" was possible.

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APPENDIX A

VTRS MOTION SEAT HARDWARE

The all-pneumatic g-cueing system assembled for this simulation consisted of:

1. Inflatable seat pan and back cushion cell assemblies installed into a Navy helicopter seat.

2. Pneumatic controller/manifolds.

3. Pneumatic regulation/distribution assembly.

4. Electronic control rack with servo control boards, microprocessor controller boards, system control panels, and keyboard terminal with tape cassettes.

The simulated motion is provided to the pilot by individually controlling the pressure in nine segmented cells in the seat pan and backrest as shown in the cushion arrangement (see Fig. A-1).

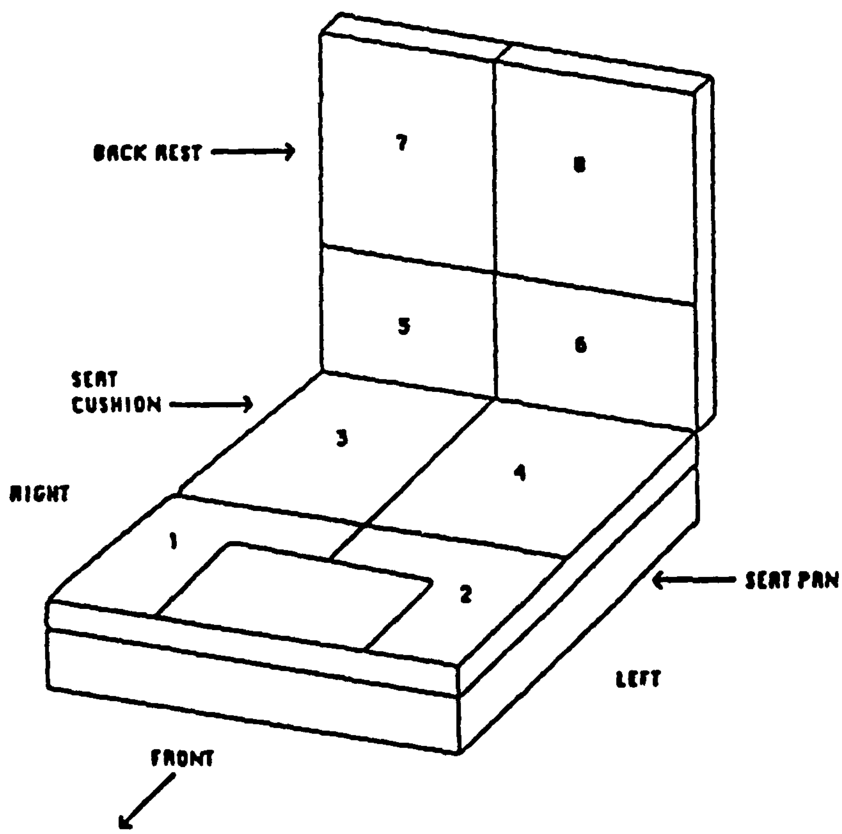

Figure A-1. Cushion arrangement.

A two-layer cushion is provided in the seat pan that consists of one large two-inch thick single cell underneath the conventional one-inch thick, four-cell cushion. The backrest has only a similar one-inch thick, four-cell cushion. Each cell is made from AIRMT (Tm) (the upper and lower surfaces are joined by inner threads), and each cell has a pressure feedback transducer. Closed-loop servo control of each individual cell pressure is used. By proper modeling, it is possible for the pilot to receive cues related to pitch, roll, yaw, heave, and fore/aft motion. Passive thigh wedges are incorporated in the outer edges of the four-cell seat pan cushion so that the pilot can also feel sensations or changes in outer thigh pressure (indicative of lateral motion cues) when the cushions are energized.

The two-inch thick, single cell cushion in the seat pan is used for providing additional pure heave motion, especially for proper pilot eyepoint motion.

APPENDIX B

PILOT OPINION QUESTIONNAIRE

Instructions for the Debrief Questionnaire

In this questionnaire we ask you to think carefully and critically about the effect any factor may have had on your performance in the simulator. The factors are features we are interested in, such as field of view or scene detail. Some factors may have had larger effects on your performance than others and your opinions on the nature of these effects, as well as any other comments you may wish to include, would be helpful.

Two levels or options were manipulated within each factor. You will be asked to compare the options in each of the various conditions in terms of the effects that each option had on your performance. It is possible that you did not recognize a difference between the options, and if this was the case, please indicate so.

Please be specific and thorough in your answers and do not leave any questions unanswered. If you are unsure about the meaning of any of the questions, feel free to ask the experimenters for verification.

The staff at VTRS would like to thank you for your participation in this experiment and your contribution to scientific research. We wish you the best of luck in all future endeavors.

Approach, Hover, and Landing Task

DEBRIEF QUESTIONNAIRE

Please rank order (1 = large; 5 = small) the following simulator features in terms of the effect they had on your performance:

Scene Detail	__________
Field of View	__________
Dynamic Cueing (G-seat)	__________
Dynamic Inflow	__________
Seastate	__________

Circle one option from each set to complete the following sentence:

My performance was better with the ____________________.

1.	Detailed Scene	vs.	Sparse Scene
2.	Wide Field of View	vs.	Small Field of View
3.	Dynamic Cueing (G-seat) On	vs.	Dynamic Cueing (G-seat) off
4.	Dynamic Inflow	vs.	Dynamic Inflow Off
5.	Seastate On	vs.	Seastate Off

Please answer each of the questions on the following page in as much detail as possible.

Dynamic Inflow: Dynamic Inflow On vs. Dynamic Inflow Off

a) The difference between factor levels on performance was:

EFFECT (Circle One) Large Moderate Small None

b) Which aspects of performance were affected by the dynamic inflow?

____

____

c) Which segments of the task were affected by the dynamic inflow?

____

____

1	2	3	4	5
Very Poor	Inadequate	Acceptable	Good	Excellent

	Fidelity	Adequacy for Training	Adequacy for Skill Retention
d) Inflow ON	________	________	________
e) Inflow OFF	________	________	________

General Comments:

____

____

____

Note: Questionnaire continues in a similar manner for the other factors in the experiment.

Precision Hover Task

DEBRIEF QUESTIONNAIRE

Please rank order (1 = large; 5 = small) the following simulator features in terms of how the effect they had on your performance:

Scene Detail ________

Field of View ________

Visual Transport Delay ________

Dynamic Cueing (G-seat) ________

Dynamic Inflow ________

Circle one option from each set to complete the following sentence:

My performance was better with the ________________.

1.	Detailed Scene	vs.	Sparse Scene
2.	Wide Field of View	vs.	Small Field of View
3.	117 msec Delay	vs.	183 msec Delay
4.	Dynamic Cueing (G-seat)On	vs.	Dynamic Cueing (G-seat) Off
5.	Dynamic Inflow On	vs.	Dynamic Inflow Off

Please answer each of the questions on the following page in as much detail as possible.

Dynamic Cueing: G-seat On vs. G-seat Off

a) The difference between factor levels on performance was:

EFFECT (Circle One) Large Moderate Small None

b) Which aspects of performance were affected by dynamic cueing?

____

____

c) Which segments of the task were affected by inertial cueing?

____

____

1	2	3	4	5
Very Poor	Inadequate	Acceptable	Good	Excellent

	Fidelity	Adequacy for Training	Adequacy for Skill Retention
d) G-seat ON	______	______	______
e) G-seat OFF	______	______	______

General Comments:

____

____

____

Note: Questionnaire continues in a similar manner for the other factors in the experiment.

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