A Literature Survey for Virtual Environments: Military Flight Simulator Visual Systems and Simulator Sickness

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ABSTRACT

Researchers in the field of virtual environments, or virtual reality, surround a participant with synthetic stimuli. The flight simulator community, primarily in the U.S. military, has a large amount of experience with aircraft simulations, and VE researchers should be aware of the major results in this field. In this survey of the literature, we have especially focused on military literature that may be hard for traditional academics to locate via the standard journals. We concentrate on research which produces specific, measured results that may have applicability to VE researchers. We also assume no background other than relatively basic computer graphics, and explain basic simulator terms and concepts as necessary. We have included our annotated bibliography as an appendix. The major areas we have concentrated on are:

- the effects of display parameters, including field-of-view and scene complexity
- the effect of lag in system response
- the effect of refresh rate in graphics update
- existing theories on causes of simulator sickness
- after-effects (subject experience after simulator sessions)

Many of the results we cite are contradictory — our global observation is that with flight simulator research, like most human-computer interaction research, there are very few "correct" answers. Almost always, the answer to a specific question turns on the *task* the user was attempting to perform with the simulator.

INTRODUCTION

Researchers in the field of virtual environments, or virtual reality, surround a participant with synthetic stimuli. Therefore, VE researchers must be aware of the phenomena that can occur when various aspects of the stimuli cause undesired artifacts. The flight simulator community, primarily in the U.S. military, has a large amount of experience with aircraft simulations, and VE researchers should be aware of the major results in this field. In flight simulation, the basic goal is to develop aviation skills which the pilot can then *transfer* into a real-world mission. In this paper, we present major results from the flight simulation literature having to do both with the measured success of skill transfer, and with effects such as simulator sickness and after-effects. Many of the results we found were contradictory; the specific task being performed must be taken into account when asking questions such as "how much does latency affect performance?"

The history of flight simulation dates back to 1929 when Edwin A. Link patented the first ground-based flight trainer [Stark 1992]. Stark cited 1934 as the first time the U.S. Army used simulators to train their pilots and World War II as the time when the United States and its allies purchased 10,000 "blue box" Link Trainers to teach instrument flying and radio navigation skills. Since that time, flight simulators have advanced well beyond basic instrument and radio navigation trainers. Today's simulators enable pilots to "feel" the simulated emergency in motion-based systems and conduct air-to-air combat in visually-based systems. Presently, researchers direct much of their efforts toward promoting realistic scenarios for pilot training.

Initially, many aviators were skeptical regarding the training value of simulators and preferred training in the actual aircraft. As the government trimmed operational budgets, the military needed to reduce flight training costs and directed research efforts towards cost-effectiveness studies. Orlansky and String [1977] investigated a collection of studies since 1939 and concluded simulators had significant positive effects upon training. In one study using the 2-B-24 Flight Trainer for instrument training of undergraduate helicopter pilots in the Army, Caro [1973] stated there was a "90% reduction in the amount of aircraft time to attain course objectives." Specifically, Caro [1972] showed that previous students needed 60 hours of actual aircraft time and 26 hours in the older 1-CA-1 trainer. Upon use of the 2-B-24, students now achieved the same training goals in only 6.5 aircraft hours and just under 43 simulator hours on average. Orlansky and String's results were instrumental in promoting simulator use. They concluded that "hourly operating costs of flight simulators were approximately 5% to 20% of the hourly operating costs of the aircraft they emulate." They also predicted that military flying hours would be reduced to almost 17 percent by 1981, and that the procurement cost of these simulators could be amortized in 2.2 years. Consequently, the military strongly encouraged flight simulator use in all areas of training. Today, simulators serve as a major training resource for the United States military services and many commercial aviation companies.

Despite the cost benefits of training in simulators over the actual aircraft, pilots experience a phenomenon called simulator sickness which is not present in the actual aircraft. Simulator sickness is a common side-effect for many users which is often associated with motion sickness. Kennedy and Frank [1985] describe motion sickness as a general term for a collection of symptoms one experiences when subjected to abrupt, periodic, or unnatural accelerations, and common symptoms include: loss of skin color, inability to coordinate voluntary muscular movements, and nausea. The term simulator sickness is typically used to refer to sickness caused by the *incorrect* aspects of the simulation, not sickness caused by a correct simulation of a nauseating experience, such as a turbulent airplane flight.

There are subtle differences between motion sickness and simulator sickness. For instance, Casali [1986] concluded from research conducted by Money (1970), that it is "...generally accepted that stimulation of the vestibular apparatus of the inner ear is necessary for the inducement of motion sickness in humans." Daunton, Fox, and Crampton [1984] showed that the symptoms of motion sickness, along with the illusions of self-motion, can be elicited in human subjects by visual stimulation alone. This phenomenon of visually induced motion sickness (VIMS) is an example in which the user becomes sick without any vestibular stimulation, and, although the symptoms are similar to those of motion sickness, VIMS is an example showing how simulator sickness can be distinct from motion sickness. Kennedy, Frank and McCauley [1985b] best depict these subtleties via a diagram showing a schematic relationship among simulator sickness, motion sickness, and perceptual adaptation, which is simply the ability of the human central nervous system to adjust and respond to a stimulus better the next time it is encountered. The diagram illustrates that although there exists overlap among each of the three, each also has its own unique characteristics. Later, Cheung, Howard, and Money [1991] identified another issue asserting, "Labyrinthine-defective subjects [those with inner-ear damage] experience no sickness symptoms, which strongly suggests that the vestibular system is necessary for sickness induced by moving visual fields."

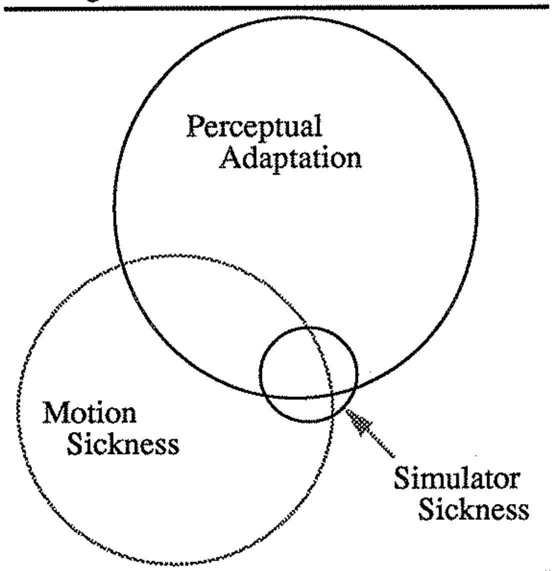

Figure 1: Reproduced from Kennedy, Frank and McCauley [1985b]

The origins of simulator sickness are unclear and no single factor appears to cause illness in all simulators. Sickness may arise as a result of unique, individual factors or because of improper simulation from the hardware device. Some, but not all, symptoms of simulator sickness are identical to those of motion sickness. Kennedy and Frank [1985] describe simulator sickness as both polysymptomatic (many symptoms) and polygenic (many distinct sources). For instance, whether the simulator device is a moving or motionless platform is one possible source, and it has been well documented that a motion system operated at a frequency of 0.2 Hz (cycles/second) is more likely to induce sickness than at other frequencies [Kennedy, et. al, 1987]. Another primary source of stimuli is the visual imagery in the simulator.

VISUAL SYSTEMS

Many of the characteristics of a simulator's visual display system can be described on two levels: a quantitative, physical level and a qualitative, psychophysical (or perceptual) level. These qualitative measures are more intuitive human perceptual measurements as opposed to quantitative physical measurements. A 1981 Advisory Group for Aerospace Research and Development (AGARD) paper, "Characteristics of Flight Simulator Visual Systems", described the display system in detail and discussed three basic characteristics of visual systems: energy, spatial, and temporal properties.

ENERGY PROPERTIES

Several energy properties pertaining to flight-simulator visual systems include:

- luminance,
- contrast,
- resolution, and
- color.

The energy properties listed are the physical measurements of the hardware device which are not fully understood by most people. Understanding these properties is important towards recognizing how the visual display system corresponds to the human visual system. For instance, luminance may not be understood by many, but the psychophysical (perceptual) correlate of light is common to most. Light is a familiar concept and most people see it on a daily basis, while luminance is the energy property which was measured in candela/meter^2, or the light emanating from various types of standard candles. Today, it is measured by the amount of light emanating from a blackbody surface at the temperature of melting platinum [AGARD 1981]. Another psychophysical term is visual acuity, which is the ability of the human eye to recognize fine detail. For instance, the more dots/inch an individual can distinguish, the better his or her visual acuity. Resolution, on the other hand, is the level of small, recognizable details at which a device can represent an image. A CRT which is able to represent 500 pixels/inch has greater resolution than a CRT which represents 100 pixels/inch. Light or brightness correlates to luminance and visual acuity correlates to resolution. Light and visual acuity are what the human perceives, and luminance and resolution are the actual physical measurements.

It is important to view the energy properties of visual displays with the following in mind. Luminance, contrast, and resolution are very much interrelated and cannot be considered in isolation of each other. Otherwise, any adjustment of one of these variables without a corresponding adjustment of the other two will result in an improper visual display. Consequently, these properties must be carefully balanced with the task to be performed and the capabilities of the human visual system in order to achieve optimum performance [AGARD 1981].

Color is an energy property whose value concerning user performance is uncertain. "Whether color should be used in visual systems is a debatable question. There is little experimental evidence of its effect, and presently no substantial objective evidence either for or against the use of color in visual flight simulators" [AGARD 1981]. In a study of bombing performance in the 2B35 TA-4J flight simulator, Kellogg, Kennedy, and Woodruff [1984] determined there were no statistically significant differences between performance with color and black-and-white visual displays. They concluded that color visual scene presentation did not enhance performance, and determined that the only advantage was that pilots preferred the aesthetic considerations of color. Despite the fact that "the highest resolution color television display has significantly lower resolution than many monochrome displays," there is a subjective preference of color over monochrome [AGARD 1981]. Also, if tasks depend on rapid discrimination of objects, color may provide benefit: "An object is more easily recognized in color than monochrome... in a projected image of the sky and ground, if the sky is blue and the ground is brown/green, the pilot will rarely mistake his orientation, even in violent combat maneuvers" [AGARD 1981].

SPATIAL PROPERTIES

Several spatial properties pertaining to flight-simulator visual systems, include:

- field-of-view
- viewing region
- depth perception
- scene content.

Field of View

Field of view is a spatial property that defines the horizontal and vertical dimensions of the display screen in terms of angles from the design eyepoint. In general, findings show that wider field-of-view displays tend to enhance performance while also increasing the likelihood of simulator sickness, but studies reveal are inconsistent across various systems.

Research conducted at the Naval Training Systems Center's (NTSC) Visual Technology Research Simulator (VTRS) studied field-of-view and considered its effect on performance relative to cost-effectiveness, incorporating simulator sickness as a variable in the conclusions. In two carrier landing studies, Westra et al. [1986] showed there was no transfer advantage for those trained with a wide field-of-view compared to those trained with the lower cost narrow field-of-view; Westra [1983] also showed that there were some advantages for the wide field-of-view conditions, although these effects were small and/or short lived and generally disappeared after the user completed a few trials within the simulator. On the other hand, in two other studies pertaining to helicopter shipboard landings, Westra et al. [1987] determined pilot performance was significantly better in all phases of the approach, hover, landing, and precision hover task with the wider field-of-view display; Westra and Lintern [1985] also determined field-of-view had marginal positive effects on a few performance measures.

The advantages gained from wider displays varied with each study and further depends on the task performed. Determining the correct field-of-view for any particular simulator is not clear. The studies Westra and colleagues conducted at the VTRS considered transfer of training advantages relative to cost-effectiveness, and they based their recommendations on these considerations. The following discussion touches on just one aspect which should be considered when determining field-of-view effectiveness. In terms of increased simulator sickness, Van Cott [1990] showed that a wide field of view provides more stimulation and results in a more compelling display of motion. Furthermore, Kennedy, Fowlkes, and Hettinger [1989] stated that restricting the field-of-view may reduce the properties which cause nausea. These results imply that simulator sickness generally occurs more frequently with a wider field-of-view display. While the *width* of a display is a factor in determining whether people will experience illness, it should be understood that the display's field-of-view cannot be considered separately from other factors. For instance, Anderson and Braunstein [1985] demonstrated linear vection (perception of self-motion induced from visual stimulation) with a visual angle as small as 7.5 degrees in the central visual field. They achieved these results by placing observers in an environment in which they were exposed to a moving display of randomly positioned dots and concluded that motion and texture may be more critical than the size of the field-of-view. A common example of this effect occurs when movie producers show aircraft moving at very fast rates of speed, using dots or stars to simulate spaceflight.

Viewing Region

The viewing region is another spatial property which is important in that it has the limitation of producing good imagery only when viewed from within a specified region. Considering the fact that the center of the viewing region is the design eyepoint of the system, as the observer moves away from the design eyepoint, the image becomes distorted and unusable. Once you are outside the boundary of the viewing region, the imagery disappears or its quality is unacceptable [AGARD 1981].

In a cinema, the viewing region is substantially larger than that of a computer generated image. Real-image displays (screens and projectors) degrade gradually and the imagery can be useful at locations considerably distant from the design eyepoint [AGARD 1981]. On the other hand, computer-generated imagery (CGI) degrades quickly and must be properly calibrated for the design eyepoint in the virtual display. CGI displays have a smaller viewing region and any view away from the design eyepoint has implications concerning crewmember susceptibility. Lilienthal [1992] stated that "In the 2F87(F) (P-3C) simulator, the flight engineer, who was behind the pilots [location] and thus out of the design eye point of the visual system, saw distorted visual cues." He explains that flight engineers reported a significant amount of simulator sickness until they used a baffle to prevent them from having a direct view of the visual scene, and this modification reduced reports of sickness significantly. He also mentions that viewing the visual scene outside the design eyepoint causes users to see distorted visual cues which induce symptoms of simulator sickness and a lack of balance while standing.

Several of these distorted visual cues are dynamic. "Graphic displays, such as those used in flight simulator visual systems, provide accurate representations of three-dimensional space only when viewed from the geometric center of projection. If the head is moved outside the center of projection, geometric distortions occur in the projected imagery which provide inappropriate visual information for self-motion" [Rosanski, 1982, cited in Kennedy, Fowlkes, and Hettinger, 1987]. Kennedy, Fowlkes, and Hettinger also state that these optical distortions may be magnified by highly detailed imagery and wide field of view systems, and the irregularities introduced by distortions may provide inappropriate self-motion information.

Depth Perception

There are three factors important in the discussion of depth perception:

- absolute depth, or real-world distance
- relative depth, or distance between objects
- depth order, otherwise known as z-order.

Depth perception is the property of vision that allows us to see the world as three-dimensional rather than flat. Unfortunately, depth is difficult to simulate and it is difficult to build hardware that permits the use of binocular (both eyes fusing separate images) vision. Most visual systems, although they may be biocular (both eyes, same view), provide only monocular (one eye/image) cues. Although humans can adapt and use monocular cues to accomplish a variety of tasks, Hale [1987] claims binocular vision is clearly superior. Hale concluded this result via a literature review which included an article by Upton and Strothers (1972) that stated stereo viewing was superior to monocular viewing. In Hale's review, another paper by Martin and Warner (1985) compared four different field of view angles: 40 degrees monocular, 40 degrees binocular, 90 degrees binocular, and 120 degrees binocular. The subjective response from the questionnaire indicated a progressive increase in pilot ratings from the 40 degrees monocular field-of-view to the 90 degrees binocular field-of-view for various aspects of the mission. There was very little difference in ratings between the 90 degrees binocular and 120 degrees binocular field-of-view. Martin and Warner indicated this may suggest that increasing the field-of-view beyond 90 degrees will not significantly improve pilot performance.

Scene Content

Scene content is a spatial property that simply refers to the level of detail available for the given scene. There are varying reports on the performance advantages of scene detail depending on the task performed and the study. The conclusions Westra and colleagues reached with the carrier landing studies indicate scene detail had very small effects, and the helicopter shipboard landing studies indicate a range of small to large effects. Specifically, Westra et al. [1987] stated that the "largest" scene detail effects occurred during the approach, hover, and landing phases. A possible explanation for this is that the takeoff and landing tasks performed by any pilot typically require greater concentration than normal in-flight tasks.

TEMPORAL PROPERTIES

Temporal properties are potentially the most important aspects of a simulation (or Virtual Environment) system, but they are also among the most difficult to measure. Temporal properties include:

- lag
- time lag

- refresh rates
- update rates

Lag is the effect that the CRT cannot completely discharge the image before the scan of the "next" image. If lag is excessive, it will cause smearing of a moving image and after (old) images may be visible [AGARD 1981]. This *lag* is associated with the rate at which the phosphor dissipates; more on this topic in the section on refresh rates.

Time Lag

Although time lag may refer to either the instrument, motion, or visual system, most research concerning time lag pertains to the motion and visual systems. Our discussion will focus once again on the visual system for previously stated reasons, that is, the majority of information we receive is from visual stimuli. Frank, Casali, and Wierwille [1988] confirm this point as they cite Newell and Smith (1969), who show that our reliance on visual stimuli transfers to simulators. Frank, Casali, and Wierwille later concluded that visual delay is far more disruptive to a simulator operator's control performance and physical comfort than motion delay.

At the Navy's Visual Technology Research Simulator, Westra and Lintern [1985] compared two simulator systems in their studies of helicopter landings on small ships with system visual lags of 217 milliseconds and 117 milliseconds. They indicated that pilot performance was better with the shorter 117 milliseconds lag system, and although lag had small effects on objective performance measures, pilots noticed the increased lag and believed it had a detrimental effect on their performance.

Uliano et al. [1986] conducted another study as part of the Navy's VTRS program on three visual throughput delay systems with varying amounts of lag at 215 +/- 70 milliseconds, 177 +/- 23 milliseconds, and 126 +/- 17 milliseconds. Here, they concluded that lag had no effect on illness in any of the conditions. They also noted that pilots were almost unanimously aware of the two longest lags, and that simulator performance was the worst under the longest lag condition.

Westra et al. [1987] conducted a second study of helicopter landings on small ships at the VTRS using system visual lags of 183 milliseconds and 117 milliseconds. Once again, they concluded that the smaller system lag had only small effects on improved performance. They also concluded that the 183 milliseconds system is marginally acceptable for performance and mentioned that there is a substantial accumulation of empirical evidence indicating increased lag contributes to deteriorated operator performance. After this study, they recommended a constant condition of 117 milliseconds for future VTRS transfer-of-training research. Within this paper, they cite Ricard et al., who "contrasted delays of 68 and 128 milliseconds and reported significantly lower error rates on all their measures of helicopter shipboard landing performance with the shorter delay." The Ricard study generated one display frame (refresh) every 33 milliseconds and they learned that a difference of 66 milliseconds (two frames) produces a "just noticeable difference" in performance effects while 33 milliseconds is less than "just noticeable".

The time lag issues discussed above deal strictly with transport delay, that is, "the time period from stick input to the completion of the first field of video output" [Westra et al. 1987]. Lilienthal [1992] recommended a limit on transport delays of 100-125 milliseconds to ensure that pilot technique is not affected by the delay, asserting that large transport delays (over 150 milliseconds.) made it difficult, if not impossible, for a pilot to adapt to the system. For large transport delays, pilots could not predict with any accuracy the length of the delay and attempts to guess and lead the system failed. As a result, pilots would overcompensate and produce oscillations, which would cause abnormal accelerations sometimes leading to sickness.

Another problem is the cue asynchrony problem, which is a greater concern in terms of simulator sickness [Lilienthal, 1992]. Lilienthal describes cue asynchrony as the difference between any two systems (i.e., motion, visual, or instruments) and recommends that the delay between any two cues be less than 35 milliseconds because "the motion cues may give the impression of motion in one direction while the delayed visual cues give the impression of motion in another direction." Kennedy, Fowlkes, and Hettinger [1989] state that there were only two experiments addressing lags and asynchronies. In the first study (Uliano et al. 1986) claim no differences in sickness ratings and in the second study (Frank, Wierwille, and Casali 1987) showed transport delays affected performance (i.e., manual control) behaviors, but the size of the delay did not affect reports of simulator sickness [Kennedy, Fowlkes, and Hettinger, 1989].

Refresh Rate

Refresh rate refers to the time it takes for the display phosphor to dissipate. The most common observance of refresh rates appears in television sets. Television displays in the U.S. operate at 30 Hz in a 2:1 interlaced mode. That is, each raster line on the screen is painted 30 times a second, such that the electron beam paints every other line during one sweep of the frame buffer, and the alternate set of lines during the next pass. The electron beam continually alternates between these sets of lines, sweeping the entire screen 60 times a second. The human visual system is generally not susceptible to flicker at 30 Hz in the fovea or central vision, however, the observer may still perceive flicker with peripheral vision. The point at which flicker becomes visually perceptible is called the flicker fusion frequency threshold. Refresh rate, brightness (light or luminance), field of view, and color are all factors that contribute to determining this threshold.

Two fundamental characteristics regarding flicker are refresh rate and brightness. As the level of brightness increases, the speed of refresh must also increase in order to suppress flicker. Also, as the speed of refresh increases, the costs increase. As a result, many users of flight simulators with slower refresh rates will reduce the visibility to dusk conditions (lower luminance) in order to prevent flicker. Further, since the peripheral visual system is more sensitive to motion than the central visual system, larger field-of-view displays increase the likelihood that the observer will perceive flicker [Lilienthal 1992]. Once again, refresh rates must increase with larger field-of-view displays in order to suppress flicker.

Slower refresh rates require more persistent phosphors which are not suitable for displaying moving images because they will cause the images to smear [AGARD 1981]. Also, slower refresh rates promote flicker which Van Cott [1990] cites as a contributor to simulator sickness. Lilienthal [1992] also states that flicker is distracting, induces eye fatigue, and appears to be associated with simulator sickness, and that if the cost of refresh rates are too high, then the trade-off should be made with luminance specifications.

There are two general categories of flicker in the literature. Small-field flicker which refers to elements in single lines or small groups of lines corresponding to the central visual system, and large-field flicker which refers to all portions of the display and the peripheral visual system. Large-field flicker appears as random movements across the display and is more objectionable than small-field flicker [AGARD 1981]. Kennedy [1990] supports this argument and found that large-field flicker may be interpreted as motion in the background, and the discomfort reported from flicker may cause sickness.

Update Rate

The refresh rate indicates how often the frame buffer is examined and displayed to the screen. Update rate refers to the generation frame rate or the frequency at which complete images are generated and rendered into the frame buffer for display. Unlike refresh rate, which is a hardware-determined constant, update rate can vary dramatically based on scene complexity and other factors.

SIMULATOR SICKNESS

GENERAL FINDINGS

Havron and Butler (1957) and Miller and Goodson (1958) were the first pairs of researchers to mention the phenomenon of simulator sickness by name [Frank et al. 1983]. Research on simulator sickness steadily increased through 1980, and then reported incidents nearly doubled by 1985 [Kennedy and Frank, 1985]. A majority of the reports investigate the commonality of simulator sickness and the percentage of the population that actually experiences the illness. The reported rate of incidence varies, as Casali and Frank [1987] point out in their review of the literature which documents incidence rates ranging from 0% to nearly 90% in flight devices and even higher in some ground vehicle devices. Kennedy, et al. [1987] provide more concise results taken from U.S. Navy studies conducted over a two year period at ten flight simulator sites. These studies showed less variation, with incidence rates ranging from 12%-60% at these simulators.

Several studies have attempted to determine whether certain individuals or groups of individuals were more susceptible than others. For example, Kennedy, et. al [1987] claim that "perhaps as much as 80% of the simulator sickness problem resides in perhaps 20% of the population." They later went on to say that "only about 30% of the individuals become ill under even the worst simulator conditions." In an attempt to isolate various individual sources, Kennedy and Frank [1985] address several, including gender, age, and physiological condition.

SPECIFIC FINDINGS

Regarding gender, Kennedy and Frank [1985b] claim that women are more susceptible to motion sickness than men. They mention a postulate concerning motion sickness which stated "that perhaps hormonal influences are at play, since women are most susceptible during their menstrual cycle (Schwab, 1954)." More importantly, they noted that women exhibit larger fields of view than men, and it is a well documented fact that simulator sickness appears more prevalent in simulators with wide fields of view.

Kennedy and Frank [1985] address age as a factor and state that susceptibility is highest for individuals from about two years of age through puberty. Then, susceptibility rapidly decreases through age 21, decreasing gradually thereafter, and almost disappears at age 50.

Illness is another factor which increases a person's susceptibility to simulator sickness. Previously, Frank et al. [1984] addressed the physiological state of the individual and advised against using the simulator if the subject was ill. Other reasons to avoid simulator use include fatigue, sleep loss, hangover, upset stomach, periods of emotional stress, head colds, ear infection, ear blocks, upper respiratory illness, and current medication. They further recommend not using simulators more than necessary when suffering from the effects of flu or possibly after receiving a flu shot, primarily because the literature on motion sickness and vomiting show that these symptoms are cumulative [deWit, 1957 and Cordts, 1982, cited in Frank, et al., 1984].

Gender, age and physiological condition are only a few of a larger number of individual sources which could be considered when studying simulator sickness. Crewmember position and experience are two other sources, and the following breakdown of these issues may better reveal the complexity of simulator sickness and explain why the origin is so elusive.

Casali and Wierwille [1986] looked at crewmember susceptibility and point out that simulator-induced sickness may be a function of the aircrew member's position in the simulator cockpit. An explanation for fewer pilot incidences than co-pilot or other crewmembers may be due to the amount of control the participant exercises. Lackner [1990] found that when subjects generated input themselves they were less susceptible to motion (simulator) sickness. He makes the point that the person controlling or anticipating the motion (simulator) becomes sick less often than the passengers, a phenomenon similar to the experiences of many automobile passengers whose car sickness diminishes when they are the driver. Another explanation might be the participants position in the simulator relative to the optimal viewing position, or the design eyepoint. There is only one design eyepoint in a simulator, and as you move away from this point it is more difficult to view the imagery. In two pilot cockpits, the design eyepoint is usually located between the two pilots or at the pilots station. Consequently, the further a crewmember is away from the design eyepoint, the greater the chances for sickness.

The level of previous experience is another source from which to study simulator sickness and the evidence here is inconclusive. Kennedy, et al. [1987] believe that more experienced pilots have greater difficulty than novice pilots, and they cite Havron and Butler (1957), Miller and Goodson (1960), McGuiness, Bouwman and Forbes (1981), and Kennedy (1981) whose studies support this argument. Specifically, they state that Miller and

Goodson found 60% of the instructor pilots reported symptoms as compared to only 12% of the student pilots, and McGuiness, Bouwman and Forbes concluded that the more experienced aircrews [over 1500 flight hours] had a higher incidence of symptoms than the less experienced flight crew. On the other hand, Magee, Kantor, and Sweeney [1987] stated there was no evidence to indicate that experience influenced susceptibility to simulator sickness. This issue of these inconsistent definitions for novice came up at the 1988 Advisory Group for Aerospace Research and Development (AGARD) conference during the concluding round table discussion. In the Magee, Kantor, and Sweeney study, novice pilots were those who were new to the C-130 aircraft, but averaged 1500 flight hours, while previous studies defined novice pilots as those who had little or no total flight time. The outcome of the discussion was that the AGARD committee generally accepted novice to mean little or no flight experience. As a result, the committee recognized that more experienced pilots tend to experience greater difficulty than novices, and that the different criterion used explained the varying results.

The fact that experienced pilots have greater difficulty might be explained from several points already mentioned. Since more experienced pilots have clearer expectations of what should happen in the aircraft compared to the novice, an incorrect signal received by the experienced individual may also result in a greater mismatch discrepancy than for the novice. Further, since student pilots (novices) tend to handle the flight controls more than the instructor pilots (experienced), they may be less susceptible because they control the input to the system. Finally, if the optimal position is placed at the student pilot's location, this would be one explanation for the higher incidence rates for instructor pilots.

THEORIES

After introducing several generic sources for individual difference in susceptibility, Kennedy and Frank [1985] reviewed a number of theories attempting to explain the origin of motion sickness that surfaced in the literature. These theories include:

- vestibular (inner-ear) overstimulation
- fear/anxiety
- toxic reaction
- fluid shift
- perceptual conflict

The final theory, "perceptual conflict" proposed by Steele in 1968, is also known as the "sensory conflict" theory or the "cue-conflict" theory. This theory addresses the mismatch that occurs when one expects certain things to happen based upon previous experience, yet the visual or vestibular signal received produces a mismatch or conflict. Van Cott [1990] described this theory as sickness that arises when "motion information from vision, the vestibular system, and proprioceptors (sensory receptors) may be in conflict with the expected values of these inputs derived from past experience." Although this theory does not answer every possible source of simulator sickness, it is presently the most widely-accepted working model explaining the illness. Cheung, Howard, and Money [1991] support the Kennedy and Frank conclusions concerning the vestibular system and simulator sickness, and their conclusions are consistent with the theory of sensory conflict.

SIMULATOR USAGE

ADVANTAGES AND DISADVANTAGES

The advantages mentioned previously include the success of transfer of training, that is, the carryover of those tasks learned in the simulator to the actual aircraft, and the cost-effectiveness gains. For additional transfer of training information, the reader should look at Waag's [1981] review of the literature concerning the training effectiveness of visual motion, or a collection of nearly 150 extracts compiled by Ayres et al. [1984]. Additionally, Stark [1992] provides pointers to papers on transfer of training. When considering the disadvantages of simulators, Frank, et al. [1983] first addressed a few key negative implications which they grouped into three broad areas concerning sickness. These are simulator after-effects, decreased simulator use, and compromised training.

DISADVANTAGES

After-effects

An initial look at simulator after-effects reveals that exposure to the simulator may result in future safety concerns. If an individual experiences side-effects (loss of skin color, sweating, nausea) as the result of a simulator session, the consequences of operating another vehicle such as a car or the actual aircraft after simulator exposure could be hazardous. Many of the reports on after-effects include examples where the user receives a conflict from the orientation cues used in the simulator. Kennedy et al. [1987] tell of an incident where one individual had to stop his car on the side of the road because the after-effects of a simulator experience were so pronounced, and Kellogg, Castore and Coward [1980] cited F-4 pilots reporting delayed perceptual after-effects occurring eight to ten hours following simulator flight. These observations led to additional studies which attempted to better understand the issues of after-effects.

In one of four studies conducted with helicopter simulators, Gower, et al. [1987] revealed that nearly 40% of the AH-64 (Apache) helicopter pilots reported symptoms lasting over an hour, and 14% reported symptoms lasting longer than six hours. with helicopter pilots. In another study of UH-60 (Black Hawk) pilots, Gower and Fowlkes [1989] reported cases where individuals experienced delayed effects over 24 hours after postexposure. They concluded that approximately eight percent of the aviation population experiences delayed problems beyond the simulator session for periods that exceed six to eight hours, and an even smaller population will experience symptoms for as long as one to two days. As a result of this study, many U.S. Army aviation units adopted a policy of no aircraft flying within six hours after simulator flight.

There is a series of techniques which were successful helping pilots unable to adapt to flight simulators to overcome their experiences of simulator sickness. Dobie and May [1989] use a cognitive intervention program in which participants receive desensitization training and/or cognitive therapy in order to inoculate individuals against motion sickness. Instead of eliminating personnel susceptible to motion sickness from flight training programs, they received a number of potential students that would have been eliminated from the flight training program and their treatment resulted in 86% of trainees returning to flight training without any further significant signs of airsickness for these individuals.

Decreased Use

Decreased simulator use is another concern of Frank, et al. [1983]. If simulators produce unpleasant side effects, they may not be used because people will lack confidence in the training they receive. The effort to produce the most realistic simulator continues to be an active area of research. Several variations include simulators that may or may not include motion and/or visuals.

Compromised Training

Training in the simulator can be compromised in a number of ways, including fatigue and adaptation. Frank, et al. [1984] mention that simulator sickness symptoms may cause distractions and therefore interfere with learning. They refer to this as fatigue-decreased proficiency, which describes use of a simulator when fatigued, whether upon entry or after exposure to the simulator during the training period results in reduced proficiency. Ebenholtz [1990] claims that once the user experiences fatigue, the potential for positive learning effects from the simulator is decreased. Hamilton, et al. [1989] showed that over 50% of tested aircrews experienced increases in simulator sickness symptom frequency following training, with the most commonly reported symptoms being mild mental fatigue, physical fatigue, eye strain and after sensations of motion. The CH-47 (Chinook) Flight Simulator study conducted by Gower and Fowlkes [1989] also showed eyestrain and headache as the leading symptoms of asthenopia, a term optometrists use to refer to many eyestrain problems.

Adaptation

The capability of humans to adapt (perceptual adaptation) to simulation deficiencies can be a problem. It is possible that an individual might use techniques to avoid simulator sickness which may be detrimental if they transfer these techniques to the actual aircraft. For example, many pilots restrict their head movement while in the simulator to avoid what is known as pseudo-coriolis effect. The Coriolis force is an apparent force that as a result of the earth's rotation deflects moving objects (as projectiles or air currents) to the right in the northern hemisphere and to the left in the southern hemisphere. "In simulators, large rapid head movements during angular motion of a simulator can cause vestibular coriolis effects, while head movements during visually represented angular motion can cause pseudo-coriolis effects" [Van Cott, 1990]. Lackner [1990] discussed how provocative effects of head movement can be, but if pilots begin to restrict head movements, they may develop negative habits which may be detrimental if transferred to in-flight conditions. Any pilot who learns to restrict their head movement in the simulator will develop bad habits in terms of basic flying skills and visual contact with other aircraft, let alone any battlefield scenario amongst enemy aircraft.

CONCLUSION

Our goals with this paper was to collect together references to significant results obtained by the simulator research community. We were surprised at the current isolation between the academic computer science community and the (primarily military) simulator community, and we have collected these results, and provided our bibliography in the hopes that as virtual environments research progresses, the computer science community will be able to learn from these results, rather than re-establish them unnecessarily.

APPENDIX: ANNOTATED BIBLIOGRAPHY

BIBLIOGRAPHY

A., Martin, Edward, *Motion and Force Simulation Systems, I,* Flight Simulation Update - 1992, SUNY Binghampton - Watson School of Engineering, Binghampton, N.Y., Jan(6 -10) '92.

Discussion of perception as related to application in motion systems. Also discusses motion simulator washout.

A., Stark, Edward, *Training and Human Factors in Flight Simulation,* Flight Simulation Update - 1992, SUNY Binghampton - Watson School of Engineering, Binghampton, N.Y., Jan(6 -10) '92.

Author discusses perception and learning, tranfer of training, and gives pointers to papers that have done these studies (see papers for specific results). Then ttalks about motion perception and learning and leads towards motion systems. Includes discussion on visual simulation and visual image generation.

A., Stoffregen, Thomas, "Flow structure versus retinal location in the optical control of stance.," *Journal of Experimental Psychology. Human Perception and Performance* , no. 11, pp. 554-65 , Oct '85.

REREAD The central retina has a modest capacity to use radial and lamellar flow for the control of stance. Peripheral retina appears to be specialized for the pickup of information for postural control from flow having lamellar geometry, but it is unable to use radial flow for controlling posture at all.

A., Stoffregen, Thomas and Riccio, Gary E., "An ecological theory of orientation and the vestibular system.," *Psychological Review* , no. 95, pp. 3-14 , Jan '88.

Theory against a fundamental assumption of traditional theories of orientation. Two important areas of disagreement with the classical approach to spatial orientation. One is the nature of information for orientation, the other concerns cooperation between perception and control of orientation. Different perspective -- not sure that I agree.

Allan, J., Buffardi, L, and Hays, R., "The Relationship of Simulator Fidelity to Task and Performance Variables ," ARI Research Note 91-58 (AD-A238 941), p. 96, George Mason University, Fairfax, VA, June 1991.

Simulator fidelity should not be considered a single uniform concept, but a multi-dimensional one consisting of at least a physical and functional compooent

Ayres, Alex, Hays, Robert T., Singer, Michael J., and Heinicke, Mark, "An Annotated Bibliography of Abstracts on the Use of Simulators for Technical Training," (AD-A156 792), p. 555, Fairfax, VA, October, 1984.

Article used as a pointer for transfer of training referneces

Barrette, R., Dunkley, K., Kruk, R. , Kurts, D., Marshall, S., Williams, T., Weissman, P., and Antos, S., "Flight Simulator: Advanced Wide Field of View, Helmet-Mounted, Infinity Display System," AFHRL-TR-89-36 (?????? - Should Know), p. 232, Williams AFB, AZ, September 1990.

LIMITED Results in this report were "descriptive and qualitative rather than quantitative in nature. Citings in this report include: 30 Hz causes sickness, whereas 60 Hz does not. Stereo vision was superior to non-stereo vision. Wider fields of view were preferred, but did not necessarily result better performance than narrow FOV's. High resolution significantly better than low resolution. Binocular detection ranges were significantly better than monocular ranges. Whole section on the impact of luminance. All this in chapter 9.

Benson, A.J., "Aetiological Factors in Simulator Sickness," *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

The "mismatch" can be between concomitant inputs provided by the angular and linear acceleration transducers of the vestibular apparatus, or between visual and vestibular inputs.

, Berbaum, K.S. and Kennedy, R.S. , "An Analysis of Visual Tasks in Helicopter Shipboard Landing," EOTR-85-7 (AD-A161 101), p. 57, 1 November 1985.

VTRS experiment - Sudy goes hand-in-hand w/ (Westra and Lintern, 1984) Used Protocol Analysis technique for linking real images to virtual images. Problems: (a) all persons may not use the same visual information (b) the salience of specific sources of visual information might not be the same in novice pilots. ... may not reveal the use of visual information important for performance of the task which pilots do not consciously attend ... Augmented feedback --> supplementary visual information ... not available in the real world. Five different visual cues utilized for hover: motion parallax, interposition, shape consistency, peripheral vision in support of shape constancy, and spatial orientation and depth perception

Billman, E.R., "The Role of Adaptive Supplemental Visual Cuing in Flight Simulation," (AD-A185 932), p. 49, University of Illinois, Urbana, IL, 1987.

It is apparent from the work done here that flying an aircraft cannot be reduced to simple two-axis tracking.

Bliss, J., Kennedy, R.S., and Turnage, J.J., "Communality of videogame performances with tracking tasks.," *Perceptual and Motor Skills*, no. 73, pp. 23-30, Aug '91.

READ - NOT APPLICABLE

Bridgeman, B. and Stark, L., "OCULAR PROPRIOCEPTION AND EFFERENCE COPY IN REGISTERING VISUAL DIRECTION," *VISION RESEARCH*, no. V0031 N11, pp. 1903-1913, 1991.

The results obtained in this experiment showed efference copy to be the dominant source of information that informs both perception and visually guided behavior. Proprioception did not have an effect, at least in perception, but the slope of the proprioception function was very shallow - a large change in eye position resulted in only a small change in the proprioception signal. The function of in proprioception in perception and visual-motor coordination, then, seems to be as a backup for the principal influence of efference copy signals, though it provides a significant supplement to the registration of eye position.

C., Chung, James, Harris, Mark R., Brooks, F.P., Fuchs, Henry, Kelley, Michael T., Hughes, John, Ouh-young, Ming, Cheung, Clement, Holloway, Richard L., and Pique, Michael, "Exploring Virtual Worlds with Head-Mounted Displays," TR89-009 (AD-A208 088), The University of North Carolina, Chapel Hill, NC, February 1989.

UNREAD as of YET

C., Hebb, Richard, "Night Vision Goggle Simulation," *journal name*, p. 22, NAVTRASYSCEN, Orlando, FL, October 1991.

References to Polhemus, Private Eye.

C., Self, Herschel, "Optical Tolerances for Alignment and Image Differences for Binocular Helmet-Mounted Displays," AAMRL-TR-86-019 (AD-A174 536), p. 39, Armstong Aerospace Medical Research Laboratory, Wright Patterson AFB, OH, May 1986.

Review the literature on optical alignment and image difference tolerances for binocular devices. Tolerances for vertical and horizontal misalignment and for rotation, magnification, and luminance differences are recommended.

Caro, P.W., "Tranfer of Instrument Training and the Synthetic Flight Training System," (AD- 743 155), p. 9, Human Resources Research Organization, Alexandria, VA, March 1972.

Hard results regarding TOT data for simulators.

Caro, P.W., "Aircraft Simulators and Pilot Training," *Human Factors*, vol. 15, no. 6, pp. 502 - 509, Human Resources Research Organization, Alexandria, VA, 1973.

Study refers to his 1972 study demonstrating transfer of training.

Caro, P.W., ''Some Factors Influencing Transfer of Simulator Training,'' *Presented at Third Flight Simulation Symposium of the Royal Aeronautical Society*, p. 18, Human Resources Research Organization, Alexandria, VA, April 1976.

Transfer of training has not yet received the systematic attention it warrants. "The lack of evidence of visual display training effectiveness cannot be taken as evidence of their lack of effectiveness."

Caro, P.W., ''Factors Influencing Simulator Training Effectiveness in the U.S. Air Force,'' HumRRO FR-ED-77-18 (AD A043 119), p. 11, Human Resources Research Organization, Alexandria, VA, July 1977.

It was found that programs had not been subjected to formal evaluation studies that would establish their training effectiveness in quantitative terms.

Caro, P.W., ''Some Current Problems in Simulator Design, Testing and Use,'' HumRRO PP-2--77 (AD A043 240), p. 14, Human Resources Research Organization, Alexandria, VA, March 1977.

?

Caro, P.W., ''Aircraft Simulators and Pilot Training,'' HumRRO PP-6-74 (AD A002 614), p. 11, Human Resources Research Organization, Alexandria, VA, March 1977.

Results here were successful. 90% reduction in the amount of aircraft time required to attain course objectives. Impressive training benefits were shown when the trainer was used in conjunction with a training program incorporating the training features desribed above.

Casali, J.G., ''Vehicular Simulator-Induced Sickness, Volume I,'' NTSC-TR86-010 (AD-A173 904), p. 92, Naval Training Systems Center, Arlington, VA, 31 August 1985.

Report provides a background information on the sickness problem. The majority of the report comprises a literature review specific to simulator sickness. Most simulators incorporate displays which are bi-ocular ... The higher the scene detail, the greater the stimulation evidencing movement and vection and the greater the liklihood of a conflict with attenuated vestibular cues in the simulator.

Casali, J.G. and Rosech, R.J., ''Vehicular Simulator-Induced Sickness,'' NTSC-TR86-011 (AD-A172 990), p. 39, Naval Training Systems Center, Arlington, VA, 31 August 1986.

This report includes bibliographic listings and abstracts for those references which have direct mention of or close association with simulator sickness.

Casali, J.G. and Wierwille, W., ''Vehicular Simulator-Induced Sickness, Volume III,'' NTSC-TR86-012 (AD-A173 226), p. 155, Naval Training Systems Center, Arlington, VA, August 1986.

In terms of the display system, the use of folded reflective optics appears relatively straightforward and versatile, but the CRT's may be at the edge of the state of the art. Crewmember susceptibility - may largely be a function ofthe aircrew member's position in the simulator cockpit. Pilot experience factor - more experienced pilots are more susceptible to simulator-induced sickness. Others --

Casali, J.G and Frank, L.H, ''Manifestation of Visual/Vestibular Description in Simulators: Severity and Empirical Measurement of Symptomatology,'' *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

Recent review of the literature indicates that documented incidence rates range from 0 to nearly 90% in flight devices and even higher in some driving devices.

Chappelow, J.W., ''Simulator Sickness in the Royal Air Force,'' *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

The proportion of those suffering at least one symptom in the simulator varied between 50% and more than 90% across studies.

Cheung, B.S.K, Howard, I.P, and Money, K.E., "Visually-induced sickness in normal and bilaterally labyrinthine-defective subjects ," *Aviation, Space, and Environmental Medicine*, no. 62, pp. 527-531, (1991).

Labyrinthine-defective subjects experience no sickness symptoms, which strongly suggests that the vestibular system is necessary for sickness induced by moving visual fields. Findings are in agreement with the sensory conflict theory, that motion sickness symptomatology may be produced when patterns of visual, vestibular and somesthetic stimulation are at a variance with a neural store of expectations based on past experience.

Chung, C.S. and Berbaum, K., "Form Depth and Global Stereopsis," *??????*, no. 10, pp. 258-275, 1984.

Looked at the relationship between global and classical stereopsis. Conclusions: (1)vergence palys a critical role in the solution of randon dot stereograms but not in the solution of contoured sterograms. (2) performance with the contoured sterograms is better than with the rds in terms of both speed and accuracy. (3) in rds, discrimination of form is independent of and more accurate than discrimination of depth. (4) ... (5) ... and (finally)

Cott, Van Harold, "Lessons from Simulator Sickness Studies," *Motion Sickness, Visual Displays, and Armored Vehicle Design*, pp. 76-84, Ballistic Research Laboratory, APG, MD, Washington, DC, April 1990.

Research Findings: - sensory conflict theory is the mopst common explanation for simulator sickness. It postulates that sickness arises from a referencing function in which motion information from vision, the vestibular system, and proprioceptors may be in conflict with the expected values of these inputs derived from past experience. - a wide field of view provides more stimulation, resulting in a more compelling display of motion - Scene detail is another important variable - optical distortions have been mentioned as contributors to simulator sickness, as have poor resolution, flicker, and off-access viewing - research generally indicates that exposure duration also contributes to motion sickness - in simulators, large rapid head movements during angular motion of a simulator can cause vestibular coriolis effects, while head movements during visually represented angular motion can cause psuedo coriolis effects.

Crosby, J.V., Pohlman, L.D., Leshowitz, B., and Waag, W.L., "Evaluation of Low Fidelity Simulator (LFS) for Instrument Training," (AD-A058 139), p. 14, HQ Air Force Human Resources Laboratory, Tempe, AZ, July 1978.

LFS trained group performed significantly better than the control group across all maneuvers. Analysis of the collected data during T-4 training revealed significantly fewer trials to criterion for th eexperimental groups. On the second ASPT sortie, however, no differences were found between the groups. Likewise, the data collected during the T-3 training revealed no differences. The results indicated a considerable amount of positive transfer at the onset of the UPT program. These initial performance differences, however, appeared to wash out following approxiamtely one month of academic and T-4 simulator training. Beyond this point, no differences between the groups could be detected.

Cross, K.D. and Gainer, C.A., "An Enumeration of Research to Determine the Optimal Design and Use of Army Flight Training Simulators," Technical Reprt 763 (Ad-A191 242), p. 207, US Army Research Institute for the Behavioral and Social Sciences, Fort Rucker, AL, October 1987.

Visual systems/cockpit displays and controls

Daunton, N.G., Fox, R.A., and Crampton, G.H., "Susceptibility of Cat and Squirrel Monkey to Motio Sickness Induced by Visual Stimulation: Correlation with Susceptibility to Vestibular Stimulation ," *AGARD Conference Proceedings No. 372 -- Motion Sickness: Mechanisms, Prediction, Prevention and Treatment*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, May 1984.

It is well known that symptoms of motion sickness, as well as illusions of self-motion can be elicited in human subjects by visual stimulation alone.

Dixon, K.W. and Curry, D.G., "Weapons Delivery Training: Effects of Scene Content and Field of View ," AFHRL-TP-88-29 (AD-A227 968), p. 17, Operations Training Division, Williams AFB, TX, November 1990.

Neither the scene content nor the FOV variable afected the number of trials to reach proficiency. Even though there were no strong and consistent effects in bomb scores, the overall performance of subjects was

better in training conditions that incorporated familiar objects and vertical development in that greater adherence to the desired profile occurred in the test condition for pilots trained in these conditions. There was also better performance for ful-FOV display. This leads us to believe that tasks requiring close adgerence to a flight profile should use full-FOV displays and incorporate vertically developed cues.

Dizio, P., "MOTION SICKNESS SUSCEPTIBILITY IN PARABOLIC FLIGHT AND VELOCITY STORAGE ACTIVITY ," *AVIATION SPACE AND ENVIRONMENTAL MEDICINE*, no. V0062 N4, pp. 300-307, 1991.

RE-READ Paper attempts to identify potential links betweeen vestibular processing of head movements and space motion sickness. The extent of dumping and the severity of motion sickness is elicited by post-rotary head tilts depended on the background force level. Major findings are that motion sickness susceptibility of subjects who are allowed unregulated movement in parabolic flight shows a slight positive correlation with the time constant of decay of slow phase eye velocity following vertical axis sudden stop simulation in 1G. Assessment of motion sickness may reflect the provocativeness of factors in addition to head movements per se, such as variations in background linear acceleration or self-limiting of head movements. In summary, we have shown that there is a highly significant, positive correlation between motion sickness susceptibility during unregulated head movements in parabolic flight and the extent to which head movements suppress the postrotary vestibulo-ocular reflex under groun-based conditions.

E., Money, K, Cheung, B S., and Kirienko, N M., "An illusion of reversed direction in hyperopes.," *Perceptual and Motor Skills*, no. 65, pp. 615-18 , Oct '87.

Farsightedness - as an object moves across a FOV, there is an illusion of reversed direction - hyperopes

Ebenholtz, Sheldon, "Oculomotor Factors and Design Requirements," *Motion Sickness, Visual Displays, and Armored Vehicle Design*, pp. 18-27, Ballistic Research Laboratory, APG, MD, Washington, DC, April 1990.

Very good explanation of asthenopia and why/how these stresses affect pilots as they do. Aricle gives good background as far as physioloical issues and fatigue.

Fichten, M.A., Jennings, D.H., and Zyda, M.J., "Meaningful Real-Time Graphics Workstation Performance Measurements," NPS52-89-004 (AD-A202 050), p. 135, Naval Postgraduate School, Monterey, CA, November 1988.

Four levels of graphics system performance measurements: One of the major changes from our previous simulators that we made for MPS was the utilization of Z-buffering for all hidden surface elimination. Previous simulators relied on scan-line hidden surface elimination algorithm performed by the CPU. The scanline algorithm greatly complicated the simulators's software and made it less supportable over the long run. It turns out that selecting Z-buffering for all hidden surface elimination at thisa time is fortuitous as Z-buffers have just become fast enough to beat older our scanline algorithm. We did this because on the IRIS 4D/70GT an infinite light source with an infinite viewer is free timewise when Z-buffering is turned on.

Frank, Lawrence, Kennedy, Robert S., Kellogg, Robert S., and McCauley, Michael E., "Simulator Sickness: A Reaction to a Transformed Perceptual World: I. Scope of the Problem," (AD-A192 438 (NAVTRAEQUIPCENT-65)), p. 10, Orlando, FL, April 29, 1983.

Hard Facts: Kellogg, Castore and Coward (1980) - 88% of (48) pilots experienced some symptoms of simulator sickness during SAAC training. F-4 pilots reported delayed perceptual aftereffects occurring eight to ten hours following simulator flight. SAAC - Simulator Air-to-Air Combat Money (1980) - nearly half the pilots using the Aurora simulator experienced sickness ... McGuiness, Bouwman & Forbes (1981) - 27% of the aircrews using the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) experienced sickness. "The more experienced aircrews (over 1500 flight hours) had a higher incidence of symptoms than the less experienced flight crew. Frank (1981) - almost one out of every ten individuals using the F-14 2F112 experienced symptoms and close to 48% of the 21 aircrews sampled using the E-2C, 2F110 reported symptoms. Implications of Simulator Sickness (negative) - Compromised Training - Decreased Simulator Use - Simulator Aftereffects

Frank, Lawrence, Kennedy, Robert S., McCauley, Michael E., Root, Robert W., Kellogg, Robert S., and Bittner, Alvah C., ''Simulator Sickness: Sensiomotor Disturbances Induced in Flight Simulators ,'' *The Image II Conference Proceedings Held at Phoenix AZ*, pp. 417 - 426, Williams AFB, AZ, 30 May - 1 June 1984.

Simulator Sickness may lead to decreased simulator use, distrust of the training received, and post-effects which may place the individual at risk in real-life situations. Kellogg, Castore and Coward (1980) - 88% of (48) pilots experienced some symptoms of simulator sickness during SAAC training. F-4 pilots reported delayed perceptual aftereffects occurring eight to ten hours following simulator flight. Aftereffects may be eight to ten hours post utilization. SAAC - Simulator Air-to-Air Combat Money (1980) - nearly half the pilots using the Aurora simulator experienced sickness ... McGuiness, Bouwman & Forbes (1981) - 27% of the aircrews using the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) experienced sickness. "The more experienced aircrews (over 1500 flight hours) had a higher incidence of symptoms than the less experienced flight crew. Frank (1981) - almost one out of every ten individuals using the F-14 2F112 experienced symptoms and close to 48% of the 21 aircrews sampled using the E-2C, 2F110 reported symptoms. Implications of Simulator Sickness (negative) - Compromised Training - Decreased Simulator Use - Simulator Aftereffects the two visual systems (focal/ambient, Leibowitz & Post, 1982) and vestibular info ... a frequency resonance of about .2 Hz (McCauley & Kennedy, 1976: Money, 1970) suffering from the effects of flu (flu shot?), hangover, etc., because in the literature on motion sickness and vomiting, these symptoms have shown to summate (deWit, 1957; Cordts, 1982)

G., Ancman, Eileen, ''Perpetual Limitations of Peripherally Displayed Colors on CRT's,'' (AD-A236 289), p. 43, Wright Laboratory, Wright Patterson AFB OH, March 1991.

The results of this study will be used to determine the best cockpit format color usage for retrofit and future aircraft designs.

G., Dobie, Thomas, May, James G., Fisher, Wanda D., and Elder, Thomas, ''A Comparison of Two Methods of Training Resistance to Visually-Induced Motion Sickness,'' NBDL-87R004 (AD-A231 806), p. 11, Naval Biodynamics Laboratory, New Orleans, LA, 1 October 1990.

The findings of this study support the efficacy of cognitive-behavioral therapy for increasing tolerance to stimulation which elicits motion sickness. Although cognitive-behavioral therapy procedures resulted in significant increases in tolerance, the precise reason for this is not clear.

G., Dobie, Thomas, May, James G., Fisher, Wanda D., and Bologna, Nancy B., ''An Evaluation of Cognitive-Behavioral Theory for Training Resistance to Visually-Induced Motion Sickness,'' NBDL-87R008 (AD-A231 807), p. 11, Naval Biodynamics Laboratory, New Orleans, LA, 1 October 1990.

The major finding in the present report supports the contention that the cognitive-behavioral treatment provides significant therapeutic support for individuals who are highly susceptible to visually-induced motion sickness. The results suggest that it is not the cognitive nor desensitization alone that increases resistance to visually induced disorientation, but the combination that is most effective.

G., Dobie, Thomas, May, James G., Dunlap, William P., and Anderson, Michael E., ''Reduction of Visually-Induced MOtion Sickness Elicited by Changes in Illumination Wavelength,'' NBDL-89R009 (AD-A232 860), p. 11, Naval Biodynamics Laboratory, New Orleans, LA, 1 October 1990.

This experiment was undertaken to assess the degree of stimulus generalization in visually-induced motion sickness. The most interesting finding was the change in motion sickness estimates within a session before and after color change. The increase within a session was greater before change than after. .. if a simulation change in the wavelength of the illumination used during VM stimulation results in a reduction in the rate at which motion sickness develops, then perhaps color changes in motion environment might increase motion sickness tolerance in real world settings.

G., Dobie, Thomas and May, James G., ''Generalization of Tolerance to Motion Environments,'' NBDL-90R010 (AD-A232 766), p. 8, Naval Biodynamics Laboratory, New Orleans, LA, 1 October 1990.

The major finding of the present study provides some supoport for the belief that tolerance acquired using one device can transfer to another motion experience. The finding that cognitive counseling in combination with visually-induced apparent motion affords considerable tolerance for that sort of stimulation is in agreement with previous reports.

G., Dobie, Thomas, "Teaching the Right Stuff - the Heart of the Matter.," NBDL-90R017 (AD-A232 766), p. 5, Naval Biodynamics Laboratory, New Orleans, LA, January 1991.

The major findings support the contention that cognitive-behavioral training provides significant therapeutic benefit for the individuals who are highly susceptible to visually-induced motiomn sickness. Cognitive treatment alone. although less effective, provided significant improvement. On the other hand, desensitization alone shopwed virtually no change. This argues for the importance of counseling approach in the treatment of motion sickness.

G., Lilienthal, Michael, *Simulator Sickness - Lessons Learned*, p. 5, July 1992. phone conversation

VERY VALUABLE INTERNAL PAPER - a number of hard facts!!!!!!!!!!!

G., Pfeiffer, Mark and Scott, Paul G., "Experimental and Analytic Evaluation of the Effects of Visual and Motion Simulation in SH-3 Helicopter Training," 85-002 (AD-B101 324), p. 62, Naval Training Systems Center, Orlando, FL, December 1985.

Transfer ratios, averaged across three criterion measures, resulted in the best transfer of training under visual+motion conditions and about equal transfer for motion only, visual-only, and no-visual/no-motion groups. Regardless of the particular device features employed, Device 2F64C significantly reduced the number of flights, flight time, and trials-to-mastery for training replacement pilots to fly the SH-3 helicopter. VISMOT feature was the condition for achieving the best transfer of training averaged across tasks. However, because of interactions, device features MOTNLY and VISMOT wrer best for trining moption based tasks and VISNLY and VISMOT wrer best for training visual based tasks

G., Pfeiffer, Mark and Horey, Jeffrey D., "Training Effectiveness of Aviation Motion Simulation: A Review and Analysis of the Literature," Special Repot 87-007 (AD-B120 134), p. 41, Naval Training Systems Center, Orlando, FL, December 1987.

Literature review of 45 transfer of training studies .. Findings for motion effects were consistent across all types of flight simulators. Accordingly, training with visual plus motion (VISMOT) systems tranferred better than the visual only (VISNLY) simulation. Similarly, training with motion (MOTION) transferred better than training with no motion (NOMOT) simulation. A separate analysis of transfer effectiveness ratios (TER's) provided results directionally consistent with the above (VISMOT > VISNLY and MOTION > NOMOT). Regardless of the particular motion features employed, most studies indicated reduced effort needed to fly the aircraft after pretraining in flight simulators. As training time in the simulator increases, the amount of transfer per hour decreases. TER - expresses the savings in transfer as a ratio of the difference between aircraft performance of control and experimental groups and a similar measure of the simulator performance of the experimental group

Gibson, R.S. and Orlansky, J., "Performance Measures for Evaluating the Effectiveness of Maintenance Training," IDA Paper P-1922 (AD-A175 351), p. 75, Institute for Defense Analysis, Alexandria, VA, September 1986.

Interpretation of any training effectiveness evaluation of a simulated maintenece trainer depends in part on an understanding of the device's behavioral fidelity on critical tasks.

Gower, D.W., Lilienthal, M. G., Kennedy, Robert S., and Fowlkes, J.E., "Simulator Sickness in US Army and Navy Fixed- and Rotary-Wing Flight Simulators," *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

Data pooled from 10 Navy simulators and the Apache CMS.

H., Frank, Lawrence, Casali, John G., and Wierwille, Walter W., "Effects of visual display and motion system delays on operator performance and uneasiness in a driving simulator.," *Human Factors* , no. 30, pp. 201-17 , Apr '88.

Visual delay appears to be more disruptive to an individual's control performance and well-being than motion delay!!! GOOD ARTICLE!

H., Owen, Dean, Wolpert, Lawrence, Hettinger, Lawrence J., and Warren, Rik, "Global Optical Metrics for Self-Motion Perception," *The IMAGE III Conference Proceedings*, pp. 406 - 415, Air Force Human Resources Lab, Williams AFB, TX, Phoenix, AZ, 30 May - 1 June 1984.

ground-speed information when the ground texture distribution is regular, but illusory information about speed when the spacing of ground elements increases or decreases. This fact may be a contributing factor in collidsions with the ground during high speed, low-level flight, especially for pilots who are more edge rate sensitive. This report also disgards the ecological approach of Stoffregen and Riccio.

H., Previc, Fred, "Towards a Physiologically Based HUD Symbology," USAFSAM-TR-88-25 (AD-A207 748), p. 19, USAF School of Aerospace Medicine, Brooks AFB, TX, January 1989.

Discussion on Global Form perception --> Anderson and Braunstein

Hale, Stephen, "Helicopter External Vision Requirements and Visual Display Characteristics: A Report/Bibliography," Technical Note 6-87 (AD-A187 075), p. 25, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, October 1987.

This was a literature search: several pointers to other papers indicating the strengths of wider field of view/binocular over narrower/monocular. Also, that stereo viewing was superior to monocular.

Hale, S., "Visual Accomodation and Virtual Images: A Review of the Issues," EFR-029 (AD-B141 629), p. 23, U.S. Army Human Engineering Laboratory, Aberdeen Proving Ground, Maryland, February 1990.

LIMITED Article contains definitions of some technical terms at the very beginning. Report discusses the central issue of the compatibility question, namely, visual accomodation to virtual images. A discussion on monocular versus binocular vision.

Hamilton, K., Kantor, L., Heslegrave, R., Magee, L., and Hendy, K, "Simulator Induced Sickness in the CP-140 (Aurora) Flight Deck Simulator," DCIEM No 89-RR-32 (AD-A213 096), p. 20, Defence and Civil Institute of Environmental Medicine (Canada), Downsview, Ontario, May 1989.

frequency following simulator training with the most commonly reported symptoms being mild mental fatigue, physical fatigue, eye strain and after sensations of motion. No difference for Novice and Experienced aircrew, nor for pilots and co-pilots. (agrees w/ a prev study, Kantor simulator exposure. The results of this study suggest that factors other than sensory conflicts were responsible for the patterns of symptoms observed.

Hennessy, R.T., Lintern, G., and Collyer, S.C., "Unconventional Visual Displays for Flight Training," TR-81-014 (AD-A111 392), p. 62, Naval Training Equipment Center, Orlando, FL, November 1981.

The general purpose of the research reported here was to examine training effectiveness for basic flight tasks of radically different methods of displaying the information that is necessary to support learning of the tasks. Pre-training with experimental displays resulted in substantial transfer savings to the control display. The hypothesis that control skills can be learned using representations of essential information that depart radically from the form found in natural scenes was supported by the results. Field of View did not importantly affect training or transfer performance of the straight and level task.

Holman, G.L., "Training Effectiveness of the CH-47 Flight Simulator," (AD-A072 317), p. 82, U.S. Army Aviation Center, Fort Rucker, AL, May 1979.

It was concluded that the Ch-47 flight simulator is an effective training device for all maneuvers tested except for those, such as hovering maneuvers, that require extensive visual ground referencing at very low altitudes. The simulator was also found to be inadequate for training night operations and terrain flying.

Howard, L.P., Cheung, B., and Landolt, J.P., "Influence of Vection and Body Posture on Visually-Induced Self-Rotation and Tilt," *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

Studied vection and illusory body tilt under all six conditions. Yaw vectio around the vertical axis was strongest. Forward pitch vection was stronger than backward pitch vection. Contrary to previous reports, for most subjects backward illusory tilt was much stronger than forward illusory tilt.

Hyman, Aaron, "Concepts for Display Interface for Battlefield Commanders," *Motion Sickness, Visual Displays, and Armored Vehicle Design*, pp. 3-17, Ballistic Research Laboratory, APG, MD, Washington, DC, April 1990.

v. general

Isley, R.N. and Spears, W.D., "Phase I Pilot Study: VTRS Transfer of Training Experiment," Seville TR 82-03 (Ad-A120 315), p. 44, Naval Training Equipment Center, Orlando, FL, March 1982.

The most important finding of the pilot study was the consistent evidence that various skills involved in approaches to the carrier became integrated. From the standpoint of possible transfer, it is the skill integration-- the behavioral process-- that is important. With sufficient integration, proper touchdowns will occur as a matter of course. They are not likely in any degree of consistency until integration has progressed.

J., Andersen, George, "Perception of self-motion: psychophysical and computational approaches.," *Psychological Bulletin*, no. 99, pp. 52-65, Jan '86.

Very Technical Paper The research was divided into two types of induced motion: rotation and translation. Two areas of of research concerned with this interaction were discussed - the study of the reflex eye movement systems that are activated by visual or vestibular stimulation, and the study of how conflicting information from the visual and vestibular systems result in motion sickness. ... visual information is the dominant source of information for determining orientation and motion of the observer. Research on induced translation has not been as extensive as that on induced rotation. The most characteristic motion is forward motion or motion in depth. ... radially expanding pattern in the central visual field and a translating pattern in the peripheral visual field...

J., Andersen, George and Braunstein, Myron L., "Induced self-motion in central vision.," *Journal of Experimental Psychology. Human Perception and Performance* , no. 11, pp. 122-32 , April 85.

Two independent modes of processing responsible for the perception of self-motion: focal and ambient modes. Results indicate the focal/ambient theory need to be reevaluated. The number of moving constants per unit time is an important variable in the perception of self-motion. An increase in induced self-motion occurs with increased velocity of the display. These results were inconsistent with those found in peripheral vision studies. The results failed to support the conclusion from previous research that visual induction of self-motion requires a large area of stimulation that necessarily involves the peripheral visual field. Strong evidence that self-motion can be reliably induced from stimulation of the central visual field with a radially expanding depth pattern. Proposed extensions to the theory of two modes of visual processing: ambient processing is served by a primitive visual system in the sense that it is primarily sensitive to low spatial frequencies. ... the addition of inconsistent motion to a display should reduce the perception of self-motion.

Jacobs, J.W., Prince, C., Hays, R.T., and Salas, E., "A Meta-Analysis of the Flight Simulation Training Research," NAVTRASYSCEN TR-89-006 (AD-A228 733), p. 55, Naval Training Systems Center, Orlando, FL, August 1990.

A meta-analysis of flight simulation research was conducted to identify important characteristicsa associated with the effectiveness of simulator training. The major finding was that use of simulators consistently improved training for jets. No conclusion about simulator effectiveness for helicopter training could be made due to the small number of experiments available for this analysis. Use of motion cuing added litt;e to the training environments for jets, and may have even detracted form training for some tasks. In general, trraining outcomes appear to be influenced by the type of task and the amount and type of training.

Johnson, K.L. and Bogumill, M.P., "F-16 & A-10A OFT Simulators Flight System Development and Test," (AD-P000 214), pp. 485-492.

This paper also contends that the greatest amount of transfer of training for flight systems operation and performance is obtained with a design philosophy which replicates cockpit features, visual cues, and the performance of the actual aircraft. The authors believe that the high fidelity flight performance and dynamics are necessary but not sufficient for high Transfer of Training.

Jr., Cullen, John K., Rampp, Randal D., May, James G., and Dobie, Thomas G, "Measures of Auditory Evoked Potentials During Optokinetic Stimulation," NBDL-87R005 (AD-A232 722), p. 4, Naval Diodynamics Laboratory, New Orleans, LA, 1 October 1990.

Current theory holds that motion sickness results from a mismatch in information derived from sensory organsinvolved in the balance and maintenance of spatial position. The results of this experiment suggest that optokinetic stimulation with or without induction of motion sickness, tends to alter the interwave interval of click-evoked auditory brainstem responses. ---> not sure I followed or want to follow

K., Gillingham, Kent and Wolfe, James W., "Spatial Orientation in Flight," USAFSAM-TR-85-31 (AD-A183 431), p. 134, USAF School of Aeromedicine, Brooks AFB, TX, December 1986.

Good description of phyiological characteristics (with regard to general understanding of the issues).

Kaempf, G.L, Cross, K.D., and Blackwell, N.J., "Backward Transfer and Skill Acquisition in the AH-1 Flight and Weapons Simulator ," ARI Research Report 1537 (AD-A213 432), p. 48, Army Research Institute for Behavioral and Social Sciences, Fort Rucher, AL, August 1989.

Comparison of the performance data from the two checkrides indicates that, while proficient on the maneuvers in the AH-1F, all IP's performed poorly in the AH1FWS. The IP's attributed their difficulties in the AH-1FWS to deficiencies in the visual system and the handling and response characteristics of the flight controls. The authors conclude that the AH-1FWS deficiencies adversely affect pilot performance on selected maneuvers. The research results provide evidence that the AH-1F aircraft and the AH-1FWS are not interchangeable training devices and that forward transfer of training research is required. Performance rated very poor on 82% of the trialsin the AH-FWS as compared to 27% in the AH-1F.

Kennedy, R.S. and Frank, L.H., "A Review of Motion Sickness with Special Reference to Simulator Sickness ," (AD-A155 975), p. 45, Canyon Research Group, Inc., Westlake Village, CA, 15 April 1985.

Title says it all: includes low frequency motion for simulators, body sway, sleep loss, adaptation issues, illness, perceptual conflict theory, gender (women more susceptible), age (2 yrs - puberty - most susceptible, decreases rapidly at about 21, almost disappears at 50), head movements, fear/anxiety theory. %A Kennedy, Robert S. %A Frank, Lawrence %A McCauley, Michael E. %D May 1984 %G AD-A210 512 %P 322 %T Simulator Sickness: Reaction to a transformed Perceptual World II. Sourcebook and Suggested Readings %X This paper traces the history of the phenumenom of simulator sickness from the time it was first reported in 1957-58. Papers include: - Barrett and Thornton, 1968 - Casali and Wierwille, 1980 - Kellogg and Castore, 1979 - Crampton and Young, 1953 - Havron and Butler, 1957 - Kellogg, Castore and Howard, 1980 - McGuiness, Bouwman and Forbes, 1980 - Miller and Goodson, 1958 - Miller and Goodson, 1960 - Reason and Diaz, 1971 - Sinacori, 1967

Kennedy, Robert, "Reconsidering Human Factors Engineering Criteria for Armored Vehicle Design," *Motion Sickness, Visual Displays, and Armored Vehicle Design*, pp. 51-63, Ballistic Research Laboratory, APG, MD, Washington, DC, April 1990.

p.56 ... if the display moves with you in ways that are different from the way real ones do, there may be vestibulo-ocular reflex (VOR) calibration. ... A wide FOV can have certain kinds of peculiar problems. Refresh rates are also a consideration. ... We think that perhaps large-field flicker may be different from small-foeld flicker, and large-field flicker may be interpreted in peculiar ways, as if motion in the background. The sickness or the discomfort reported from flicker may be nauseogenic stimulus. ... there is good evidence that the amount of acceleration at 0.2Hz is bad for people. ...Protocol Analysis

Kottas, B.L. and Bessemer, D.W., "Comparison of Potential Critical Feature Sets for Simulator-Based Target Identification Training," (AD-A128 344), p. 103, US Army Institute foor the Behavioral and Social Sciences, Fort Knox, KY, September 1980.

One can conclude from the results that highly detailed vehicle representations are unecessary for target identification training.

, BERBAUM KS--Reprint;, KENNEDY RS; , and HETTINGER LJ, "VISUAL TASKS IN HELICOPTER SHIPBOARD LANDING--English--Article," *APPLIED ERGONOMICS*, no. V0022 N4, pp. 231-239, 1991.

Used Protocol Analysis technique for linking real images to virtual images. Problems: (a) all persons may not use the same visual information (b) the salience of specific sources of visual information might not be the same in novice pilots. ... may not reveal the use of visual information important for performance of the task which pilots do not consciously attend ... Augmented feedback --> supplementary visual information ... not available in the real world. Five different visual cues utilized for hover: motion parallax, interposition, shape consistency, peripheral vision in support of shape constancy, and spatial orientation and depth perception

Lackner, J.R. and Dizio, P., "Altered sensory-motor control of the head as an etiological factor in space-motion sickness.," *Human Factors*, no. 68, pp. 784-6, 1974.

Results indicate that space-motion sickness is the result not just of unusual patterns of vestibular activation and processing, but also of altered sensory-motor control head torque.

Lackner, James, "Human Orientation, Adaptation, and Movement Control," *Motion Sickness, Visual Displays, and Armored Vehicle Design*, pp. 28-50, Ballistic Research Laboratory, APG, MD, Washington, DC, April 1990.

Lackner discusses the vestibular issues of motion sickness in depth. The effects of head movement and how provocative they can be(p. 42-43). ... issue of the problem of visual displays when there are moving elements in the display while the vehicle is also moving- moving up and down as well as turning in abgular fashion.

Lee, Task, H., "Vision Through Aircraft Transparencies," (AD-P005 786 ?), p. ?, Armstrong Aerospace Medical Research Laboratory, Wright Patterson AFB, OH, ? 1989 OR EARLIER.

Technical discussion on binocular disparity.

Lintern, G. and Kennedy, R.S., "Video game as a covariate for carrier landing research," *Perceptual and Motor Skills*, no. 58, pp. 167-172, 1984.

READ NOT APPLICABLE

Lintern, G., Wightman, D.C., and Westra, D.P., "An Overview of ," *The Image IIIConference Proceedings*, pp. 205-221, Air Force Human Resources Laboratory, Williams AFB, TX, Phoenix, AZ, 30 May - 1 June 1984.

This paper outlines significant features of the Virtual Technology Research Simulator (VRTS) and summarizes the major results. Progress towards a comprehensive specification of desirable visual display characteristics for flight training simulators has been slow and painstaking, primarily because so little is known about skill transfer and the conditions that affect it.

Lintern, G., Thomley, K.E., Nelson, B.E., and Roscoe, S.N., "Content, Variety, and Augmentation of Simulated Visual Scenes for Teaching Air-to-Ground Attack," (AD-A145 218), p. 74, Naval Training Equipment Center, Orlando, FL, July 1984.

Three factors manipulated: level of detail in visual scene, number of visual scenes, and augmented feedback. Scene content had an unexpected, but strong and consistent effect on performance and on differential transfer. Augmented feedback proved to be a potent instructional variable, but one that showed complex effects. In general, the inexperienced pilots suffered the most from limited scene content, and gained the most from augmented feedback. Nevertheless, the moderateky experienced pilots were also affected by these variables. Thus, there is no evidence in this report that pilots with no experience in air-to-ground attack should be treated differently during training to pilots who have some experience in air-to-ground attack.

Lintern, G., Roscoe, S.N., Koonce, J.M., and Segal, L.D., "Transfer of Landing Skills in Beginning Flight Training," *Human Factors*, vol. 32(3), pp. 319-327, 1990.

Experimental students required significantly fewer presolo landings in the airplane than did the paired controls, representing a potential saving of 1.5 presolo flight hours per student.

Lintern, G., Roscoe, S.N., and Sivier, J.E., "Display Principles, Control Dynamics, and Environmental Factors in Pilot Training and Transfer," (AD-A229 283), pp. 299-317, 1990.

Transfer was better following training with pictorial displays than with symbolic displays, with normal rather than reduced bank control order. This experiment was the first to offer even quasi-transfer data to support such efforts. Nevertheless, these data are from an extremely gross manipulation.

Lintern, G., "The Learning Strategies Program: Concluding Remarks," ARI Research Note 90-46 (AD-A226 016), p. 21, US Army Research Institute for the Behavioral and Social Sciences, Alexandria, VA, July 1990.

This effort has led to the development of principles at a level of abstraction that should permit effective exploitation of those principles in a wide range of operational trainning environments.

Lynn, Caldwell, Jo, Cornum, Rhonda L., Stephens, Robert L., and Rash, Clarence E., "Visual Processing: Implications for Helmet Mounted Displays," (AD-A223 488), p. 8, United States Army Aeromedical Research Laborartory, Fort Rucker, AL, May 1990.

A study was conducted to compare the performance of AH-64 (Apache) pilots to other Army pilots on visual tasks. Each pilot was presented monocularly to the right eye ... results indicated no performance difference between groups of pilots on the dichoptic task, but indicated better performance on the left moncular task for the AH-64 pilots.

M., Cardullo, Frank, *Motion and Force Cuing II,* Flight Simulation Update - 1992, SUNY Binghampton - Watson School of Engineering, Binghampton, N.Y., Jan(6 -10) '92.

Good background regarding simulators in general. Good discussion on the physiological effects of high G flight.

M., Evans, Richard, Scott, Paul G., and Pfeiffer, Mark G., "SH-3 Helicopter Flight Training: An Evaluation of Visual and Motion Simulation in Device 2F64C," Technical Report 161 (AD-B090 118), p. 46, Naval Training Equipment Center, Orlando, Fl, December 1984.

Regardless of the device feature employed, the 2F64C flight simulator significantly reduces the number of flights, flight time, and trials-to-mastery for training pilots to fly the SH-3 helicopter. Transfer ratios, averaged across the three criterion measures, resulted in the best transfer of training under visual+motion conditions, and about equal transfer for motion only and no-visual/no-motion groups.

Magee, L.E., Kantor, L., and Sweeney, D.M.C., "Simulator Induced Sickness Among Hecules Aircrew," *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

83% reported symptoms of symulator sickness. There was no evidence to indicate that experience influenced susceptibility to simulator sickness.

Martin, E.L. and Waag, W.L., "Contributions of Platform Motion to Simulator Training Effectiveness: Study I - Basic Contact," (AD-A058 416), p. 40, Air Force Human Resource Laboratory, Williams AFB, TX, June 1978.

The major findings of the study are: - no differences in simulator performance between the Motion and the No-Motion groups - significant learning occurred during simulator training for both groups - no difference in performance between the MOtion and the No-Motion groups for any of the tasks on the two special data sorties flown in the T-37 - no significant differences were found between the Motion and the No-Motion groups in the task frequency data, although there was a trend for the Motion group to perform slightly better - the two groups trained in the ASPT performed significantly better than the control group on all of the more advanced tasks.

McCauley, M.E. and Kennedy, R.S. (CDR), "Recommended Human Exposure Limits for Very Low-Frequency Vibration," TP-76-36 (AD-B015 449), p. 26, Pacifc Missile Test Center, Point Mugu, CA, 29 September 1976.

VLFV is often associated with the signs and symptoms of motion sickness ...

Mooij, H.A., ''Technology Involved in the Simulation of Motion Cues: the Current Trend ,'' (AD-B127 693), p. 16, National Aerospace Laboratory NLR, Amsterdam, The Netherlands, 30 September 1987.

LIMITED The phenomenom of "vection" ... on uniform motion of a visual field becomes effective when the Field-Of-View(FOV) is larger than 60 degrees and most effective with a FOV of 180 deg.

Orlansky, J. and String, J., ''Cost-Effectiveness of Flight Simulators for Military Training: Volume I - Use and Effectivenss of Flight Simulators,'' (AD-A052 801), pp. 97-109, Office of the Secretary of Defense, Alexandria, VA, August 1977.

The seminal paper regarding cost-effectiveness for flight simulators.

Orlansky, J. and String, J., ''The Cost-Effectiveness of Military Training,'' (AD-P000 168), pp. 97-109, Office of the Secretary of Defense, Alexandria, VA, 1979.

Flight simulators, computer-based instruction and maintenance training simulators appear to be as effective as the methods of training they can replace; they also can reduce the costs of taining. Thus, they appear to be cost-effective compared to more conventiional methods of training.

P., Westra, Daniel, Sheppard, Daniel J., Jones, Sherrie A., and Hettinger, Lawrence J., ''Simulator Design Features for Helicopter Shipboard Landings ,'' TR-87-041 (AD-A203 992), p. 61, Naval Training Systems Center, Orlando, FL, July 1987.

Scene detail and FOV design featyres are at the heart of this article. 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 high detail condition. The manipulation of visual system delay and field of view had small effects on performance. ... pilot perfomance was significantly better in all phases of the approach, hover, and landing task, and in the precision hover task under the VTRS FOV. ... 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 process that support orientation in the approach (e.g. optical flow rate). ...the nature and amount of environmental surface texture has been demonstrated to have an effect on the sensitivity to visually specified self-motion.

Prophet, W.W., ''Simulation and Aircrew Training and Performance,'' HumRRO-PP-4-74 (AD-780 688), p. 15, Human Resource Organization, Washington, D.C., April 1974.

This paper outlines some major areas of use of simulation in Army Aviation and comments on current research. Only in the training area has the Army made substantial progress.

R., McMillan, Grant, *Cue Integration and Synchronization*, Flight Simulation Update - 1992, SUNY Binghampton - Watson School of Engineering, Binghampton, N.Y., Jan(6 -10) '92.

Discusses the issues of cue integration and synchronization in terms of their effects on human sensation, perception, and performance. Good section on which cues should be integrated/omitted in a simulator. Discussions on training effectiveness, performance, and transfer of training research, and, an introduction to simulator sickness and the theory. Includes best explanation of the Riccio/Stoffregen theory!

R., Pinkus, Alan and Task, H. Lee, ''Display System Image Quality,'' (AD-P005 786 ?), p. ?, Armstrong Aerospace Medical Research Laboratory, Wright Patterson AFB, OH, ? 1989 OR EARLIER.

Good technical descriptions of CRT's, HUD's and HMD's.

, Robinett, Warren and Roland, Jannick P., ''A computational Model for the Stereoscopic Optics of a Head-Mounted Display ,'' TR91-009 (AD-A236 705), p. 21, University of North Carolina, Chapel Hill, NC, February 1991.

UNREAD article

S., Berbaum, Kevin and Kennedy, Robert S., ''Plan for Evaluation of the Training Potential of Helmet-Mounted Display and Computer-Generated Synthetic Imagery,'' (AD-A160 299), p. 53, Orlando, FL, April 29, 1985.

Description of a research plan to evaluate training effectiveness of a helmet-mounted display. Two computer-image generation (CIG) channels are incorporated which present wide-angle, low-resolution, low-

detail background and area of interestof high resolution and detail.

S., Chambers, Walter, *Visual System Overview*, Flight Simulation Update - 1992, SUNY Binghampton - Watson School of Engineering, Binghampton, N.Y., Jan(6 -10) '92.

Discussions on perception and visual image processing.

S., Kellogg, Robert, Kennedy, Robert S., and Woodruff, Robert R., "Comparison of Color Versus Black-and-White Visual Displays as Indicated by Bombing and Landing Performance in the 2B35 TA-4j Flight Simulator ," *The Image II Conference Proceedings Held at Phoenix AZ*, p. 18, Williams AFB, AZ, July 1984.

Under conditions of the study, no statistically significant differences were shown between performance with color or with black-and-white. It is concluded that color visual scene presentation, within the limits of this R&D, does not enhance performance. ... "aside from aesthetic considerations, color in flight simulation would seem to add to realism and more importantly to spatial orientation and velocity vector information available to the pilot.

S., Kennedy, R., Berbaum, K. S. , Hettinger, L.J., and Dunlap, W. P., "Short-term Solutions to Prevent Simulator Induced Motion Sickness: Report of a Conference," EOTR-87-6 (AD-A187 275), p. 194, March 1986.

The conference included interviews with many "big names" in this field. They are: - Whiteside, Thomas C.D. - Jex, Henry - Crampton, George - Reschke, Millard - Chambers, Walter S. - May, Jim - Dobie, Thomas - Ebenholtz, Sheldon - McCauley, Michael - Young, Laurence - Parker, Donald - Welch, Robert

S., Kennedy, R., Berbaum, K. S. , Lilienthal, M. G., Dunlap, W. P., Mulligan, B. E., and Funaro, J. F., "Guidelines for Alleviation of Simulator Sickness Symptomatology," (NAVTRASYSCEN TR-87007) (AD-A182 554 (NAVTRASYSCEN TR-87007)), p. 68, March 1987.

VERY INFORMATIVE PAPER Field studies over the last two years at 10 flight simulator sites showed incidence rates from 12%-60% for these simulators. No single factor has been uncovered which appears to cause illness in all simulators. simulator conditions ... in perhaps 20% of the populaution ... experiencing fatigue, sleep loss, hangover, upset stomach, periods of emotional stress, head colds, upset stomach, ear infection, ear blocks, upper rewspiratory illness, and medication. curvilinearly proportional to frequency. That is, 0.2 Hz is more nauseogenic than 0.5 Hz. are presented in the range of .13-.45 Hz in all three planes of motion velocity of edges for sny aircraft motions due to the relatively greater rates of change of visual angles subtending the objects which are depicted." important papers re: Andersen (1986) Andersen & Braunstein (1985) persons with extensive aircraft flight time, but little flight trainer time, are more prone to sickness. The evidence for more experienced pilots having more difficulty than novice poilots includes a study by Havron & Butler (1957) Miller and Goodson (1960) replicated by McGuiness, Bouman, and Forbes (1981) and Kennedy (1981) displays than in dome systems (Lilienthal, Kennedy, Berbaum, and Markle - in prep) This implies that CGI systmes are more conducive too eye strain and there sugests that the number of panels is proportional to the number of symptoms. Ryan, Scott, and Browning (1978) found evidence of drowsiness after simulator exposures ... Kellogg et al (1980) " users of such [wide-field-of-view] simulators should be aware that some adjustment may be required by pilots when stepping back into the real world from the computer-generated world ... Rosanski (1982) makes the important point that graphic displays provid eaccurate representations of three-dimensional space only when viewed from the geometric center of projection; otherwise, there are distortions.

S., Kennedy, Robert, Berbaum, Kevin S., and Collyer, Stanley C., "Spatial requirements for visual simulation of aircraft at real-world distances. ," *Human Factors*, no. 30, pp. 153-61, Apr '88.

In flight training simulators, with high resolution, luminance contrast of 25:1 produced better performance than lower contrasts.

S., Kennedy, Robert, Frank, Lawrence, McCauley, Michael E., Bittner, Alvah C., Root, Robert W., and Binks, Terrence A., "Simulator Sickness: Reaction to a transformed Perceptual World VI. Preliminary Site Surveys," *The Aerospace Medical Panel Symposium on Motion Sickness: Mechanisms, Prediction, Prevention, and Treatment at Williamsburg, Virginia on 3-4 May 1984*, p. 11, May 1984.

Hard Facts: Havron and Butler (3) published the first report of simulator sickness occurring in a flight trainer. 77% of the individuals exposeed to the 2-FH-2 trainer experienced some type of symptomatology. Miller and Goodson (4, 9) in a later study of the same simulator found that 60% of the instructor poilots reported symptomatology, as compared to only 12% of the student pilots. This finding suggests that experience may be an important factor. Kellogg, Castore and Coward (1980) - 88% of (48) pilots experienced some symptoms of simulator sickness during SAAC training. F-4 pilots reported delayed perceptual aftereffects occurring eight to ten hours following simulator flight. SAAC - Simulator Air-to-Air Combat Money (1980) - nearly half the pilots using the Aurora simulator experienced sickness ... McGuiness, Bouwman & Forbes (1981) - 27% of the aircrews using the Navy's 2E6 Air Combat Maneuvering Simulator (ACMS) experienced sickness. "The more experienced aircrews (over 1500 flight hours) had a higher incidence of symptoms than the less experienced flight crew. Frank (1981) - almost one out of every ten individuals using the F-14 2F112 experienced symptoms and close to 48% of the 21 aircrews sampled using the E-2C, 2F110 reported symptoms.

S., Kennedy, Robert, Berbaum, K. S. , Allgood, G.O., Lane, N.E., Lilienthal, M. G., and Baltzey, D.R., ''Etiological Significance of Equipment Features and Pilot History in Simulator Sickness ,'' *AGARD Conference Proceedings No. 433 Motion Cues in Flight Simulation and Simulator Induced Sickness*, Advisory Group for Aerospace Research and Development (AGARD), Neuilly Sur Seine, France, September-October 1987.

The US Navy has conducted a survey in 10 flight trainers where motion experience questionnaires and performance tests wre administered. Several findings emerged including simulator sickness incidences varied from 10-60% and substantial perceptual adaptation occurs over a series of hops.

S., Kennedy, Robert, Fowlkes,, and Hettinger,, ''Review of Simulator Sickness Literature,'' NTSC TR89-024, p. 51, Orlando, FL, 4 September 1989.

Most current review of simulator sickness literature of the Navy's 10 simulator sites and other U.S. Army and Coast Guard Simulators using the same criteria for measurements.

Sekular, R., Tynan, P.D., and Kennedy, R.S., ''Sourcebook of Temporal Factors Affecting Information Transfer from Visual Displays,'' (AD-A109 907), p. 177, U.S. Army Research Institute for the Behavioral and Social Sciences , Alexandria, VA, 1 June 1981.

This report collects in one document the important research literature on temporal factors in vision. The subject matter is perception of temporal events--specifically motion perception. Chapters on Illusion of Motion, Motion Perception in the Periphery, Flash Sensitivity, and Flicker Sensitivity.

Sheppard, D.J., Hettinger, L.J., Westra, D.P., and Jones, S.A., ''Simulator Evaluation of Lineup Visual Landing Aids for Night Carrier Landing,'' EOTR-88-1 (AD-A191 212), p. 56, Naval Air Systems Command, Orlando, FL, 10 March 1987.

Each of the VLA conditions (4) contributed some effective visual cues for one part or another of the night carrier landing task. The results of this study indicate that a low-cost simulation display containing a crossbar configuration to provide lineup displacement information contributes to improved lineup performance and does not appreciably detract from glideslope performance.

Stern, J.A. and Goldstein, R., ''An Evaluation of Electrooculographic, Head Movement and Steady State Evoked Response,'' AAMRL-TR-88-036 (AD-A236 505), p. 127, Washington University Behavior Research Laboratory, St. Louis, MO, July 1988.

A major focus was on the effect that availability of a lightweight helmet-mounted display (HMD) system had on strategies of visual information intake. Although prior laboratory work was encouraging in suggesting that steady-state potentials (photopic driving) could be established with stimulation frequencies above the flicker fusion threshold, the simulation test of those conclusions cannot be said to have been eminently successful. ... Not only are there differences among individuals in the frequency that optimally produces photopic driving, but there is reason to believe that intensity is a significant variable in determining this level.

Stewart, Rod., "Psychology of spaceflight: suggested bases of space motion sickness: perceptual disorientation and elevated stomach pH.," *Perceptual and Motor Skills* , no. 60, pp. 189-90, Feb '85.

Author discusses pH level in stomach along with prostaglandins and disorientation from motion variables.

Stewart, Rod., "Space flight: isolation of perceptual variable in parabola flight sickness with countermeasure to lower gastric pH.," *Perceptual and Motor Skills* , no. 60, pp. 960-2 , Jun '85.

Author discusses pH level in stomach along with prostaglandins and disorientation from motion variables.

Stewart, Rod., "Space flight: variables of motion sickness.," *Perceptual and Motor Skills* , no. 61, pp. 397-8 , Oct '85.

Author discusses pH level in stomach along with prostaglandins and disorientation from motion variables.

Stinnett, T., "Sensor-coupled Vision Systems," (AD-B159 536), p. 29, Westinghouse Defense and Electronics Center, Baltimore, MD, 1984.

LIMITED Experiment evaluated various FOV's and their respective performance along with the requirement cases of the head restrained and unrestrained. Mentions that the tradeoff between binocular and monocular vision will require much more study and research ... Concluded monocular viewing was much more difficult than binocular, and, caused 'both' pilots to underestimate their altitude by half. (Binocular - tendency to fly lower vs. monocular). Also, the narrower the FOV, the more difficult it became to fly the aircraft in the terrain avoidance profile (overestimated altitude). Depth perception degraded as the FOV became smaller. Extreme difficulty w/ FOV's smaller than 40 deg. Discussion on the "Bright Eye Concept".

Trautman, E., Ellingstad, V., Lilienthal, M., and Trautman, M.A., "Quasimonochrmatic Environments and the Resting Point of Accomodation ," NTSC TR 88-028 (AD-A205 938), p. 66, Naval Training Systems Center, Orlando, FL, 1988.

This investigation explored the importance of color as a factor in deterioration of correct visual accomodation and involuntary regression to the resting point of accomodation. Regression to the resting point of accomodation is not a color mediated phenomenon. Results of these and other color related investigations indicate that the human eye maintains accomodation equally well across a variety of color conditions. Ambient color of the task environment does not appear to be a design concern with respect to maintenance of optimal visual accomodation performance.

Uliano, K.C., Lambert, E.Y., Kennedy, R.S., and Sheppard, D.J., "The Effects of Asynchronous Visual Delays on Simulator Flight Performance and the Development of Simulator Sickness Symptomatology," NAVTRASYSCEN 86-D-0026-1 (AD-A180 196), p. 74, Naval Air Systems Command, Washington, D.C., 26 December 1986.

Simualtor performance was differentially affected by lag with the longest lag producing the worst performance. Of further concern, lag had no effect on any of the sickness ratings.

Umeda, A.Y., Martin, S.W., and Merrit, J.O., "Remote Vision Systems for Teleoperated Ground Vehicles," (AD-A236 765), p. ?, Naval Ocean Systems Center, San Diego, CA, May 1991.

Another study referencing FOV and stereoscopic vision advantages.

V., Parrish, Russel and Williams, Steven P, "Stereopsis Cueing Effects for Hover-in-Turbulence Performance in a Simulated Rotorcraft.," NASA TP-2980/AVSCOM TR-90-B-002 (AD-A224 484), p. 59, US Army Aviation Systems Command, Hampton, VA, May 1990.

The purpose of the effort here was to quantitatively determine the efficacy of stereopsis cuing in enhancing the situational awareness of pilots conducting precision tasks. The objective and subjective results of this experiment indictae that stereopsis cuing is an effective way to enhance situational awareness of pilots using pictorial displays.

Various, AGARD -, "Characteristics of Flight Simulator Visual Systems," *Advisory Group for Aerospace Research and Development*, no. 164, p. 90, Neuilly sur Seine, France, May 1981.

A key article by various authors discussing the topics of the title, including the energy properties of the display system, i.e., energy, spatial and temporal properties.

W., Gower, Daniel, Lilienthal, Michael G., Kennedy, Robert S., Fowlkes, Jennifer E., and Baltzey, Dennis R., "Simulator Sickness in the AH-64 Apache Combat Mission Simulator ," USAARL 88-1 (AD-A193 419), p. 49, US Army Aeromedical Research Laboratory, Fort Rucker, AL, November 1987.

This series of studies references the previous work done by the US Navy and includes the findings that emerged (p. 5). Results consistent with the Navy's findings. Study focused on the long term effects of simulator sickness and the length of time of aftereffects, i.e., nearly 40% reprted symptoms lasting over and hour, and 14% lasted longer than 6 hours. Introduces the Army policy of a 6-hour wait period in order to fly the actual A/C after flying the simulator.

W., Gower, Daniel, Fowlkes, Jennifer E., and Baltzey, Dennis R., "Simulator Sickness in the CH-47 (Chinook) Flight Simulator ," USAARL 89-28 (AD-A218 214), p. 69, US Army Aeromedical Research Laboratory, Fort Rucker, AL, September 1989.

This series of studies references the previous work done by the US Navy and includes the findings that emerged. Results consistent with the Navy's findings. Study brought up the issue of eyestrain and headache as the leading symptoms of asthenopia. Mentions the Army policy of a 6-hour wait period. (Ataxia - inability to cordinate muscle movements.)

W., Gower, Daniel and Fowlkes, Jennifer E., "Simulator Sickness in the AH-1S (Cobra) Flight Simulator ," USAARL 89-20 (AD-A214 562), p. 76, US Army Aeromedical Research Laboratory, Fort Rucker, AL, September 1989.

This report ranks the Army's flght simulators in comparison to the 10 Navy simulators studied by the NTSC, Orlando, FL. Discussion same as Apache and Chinook results.

W., Gower, Daniel and Fowlkes, Jennifer E., "Simulator Sickness in the UH-60 (Black Hawk) Flight Simulator ," USAARL 89-20 (AD-A214 434), p. 74, US Army Aeromedical Research Laboratory, Fort Rucker, AL, September 1989.

This report ranks the Army's flght simulators in comparison to the 10 Navy simulators studied by the NTSC, Orlando, FL. Discussion same as Apache, Chinook and Cobra results. Some cases reported where those using this simulator experienced delayed effects over 24 hours after postexposure. Also mentions that " part of the aviation population that experiences delayed problems beyond the simulator exposure and for periods that exceed 6 to 8 hours for approximately 8 percent of the population and 1 - 2 days for an even smaller population.

Waag, W.L., "Training Effectiveness of Visual and Motion Simulation," AFHRL-TR-79-72 (AD A094 530), p. 30, Operations Training Division - HRL, WAFB, Williams AFB, AZ, January 1981.

A review of the literature concerning the training effectiveness of visual motion simulation is presented in this report.

Webster, J.A., "Stereoscopic Full Field of Vision Video System for use in Real Time Visual Telemtry," DI-S-4057 (AD-B121 941), p. 43, DARPA, Arlington, VA, April 27, 1988.

LIMITED Paper on FOV's, update rates, and HMD's. Some specific info on FOV's.

Wells, M.J. and Griffin, M.J., "A review and investigation of aiming and tracking performance with head-mounted sights ," *IEEE Transactions on system, man and cybernetics*, no. SMC-17, No.2, pp. 210-221, Mar./Apr. 1987.

The ability to control head movements determines the performance of head-mounted sights.

Westra, D.P., "Simulation Training for Aircraft Carrier Landings," (AD-P000 204), pp. 397-404, Canyon Research Group, Orlando, FL, 1983.

Results showed that the simulator and training factors generally produced either small differences or no differences at all in transfer effectiveness. There were some advantages of the wide field of view and high-detail conditions, but these effects were small and/or short lived, generally disappearing after a few transfer trials.

Westra, D.P. and Lintern, G., "Simulator Design Features for Helicopter Landing on Small Ships ," NAVTRASYSCEN 81-C-0105-13 (AD-A169 514), p. 69, Naval Training Systems Center, Washington, D.C., 27 September 1985.

VTRS - studied the effects of six simulator features on performance, including field of view and visual lag. Transfer of training research was recommended as a follow on. Visual system lag had a moderate effect on performance especially marked by aircraft roll control with turbulence present. Field of view had marginal effects on a few performance measures with the advantage going to wide field of view.

Westra, D.P., Lintern, G., Sheppard, D.J., Thomley, K.E., Mauk, R., Wightman, D.C., and Chambers, W.S., "Simulator Design and Instrumental Features for Helicopter Shipboard Landings ," NAVTRASYSCEN 85-C-0044-2 (AD-A203 992), p. 86, Naval Air Systems Command, Washington, D.C., 18 June 1986.

A TOT experiment at the culmination of the carrier landing behaviorol research program at VTRS. There was no transfer advantage for those trained with a daytime high detail scene compared to those trained with a lower cost nighttime low-detail scene. There was no transfer advantage for those trained with a wide field of view compared to those trained with the lower cost narrow field of view scene. Transfer performance was better for the students who had 40 or 60 simulator trials than for the students who had 20 simulator trials.

Young, L.R., "Developments in Modelling Visual-Vestibular Interactions," AMRL-TR-71-14 (AD 737 795), p. 94, Whittaker Corporation, Waltham, MA, January 1971.

Detailed report on ocular issues!