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Operator/equipment Performance Measures: Results Of Literature Search

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Operator/Equipment Performance Measures: Results of Literature Search

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Operator/Equipment Performance Measures: Results of Literature Search

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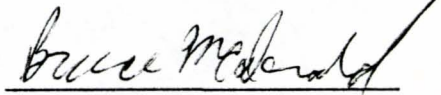


Table of Contents

<i>Section</i>	<i>Page</i>
1.0 Purpose.	1
2.0 Sources.	1
3.0 Report Organization.	1
4.0 Summary of Findings.	1
4.1 Transmission Delay.	1
4.2 Fidelity.	3
4.3 Performance Measurement and Training	4
4.4 Visual Systems.	5
5.0 References.	8
6.0 Annotated Bibliography.	16

1.0 Purpose

This literature review focused on topics concerning perception, acceptable transmission delay, fidelity, and visual systems, including resolution, field of view, and target-background contrast. The purpose of this research was to gather insight which would aid in the development of recommendations applicable to DIS. Such recommendations should yield protocol data units (PDUs) appropriate to performance measurement and some should evolve into concepts which, after laboratory testing, may be presented to DIS working groups.

2.0 Sources

The sources surveyed in this review originated from NTIS/DTIC searches and from PSYCHLIT & ERIC CDROM searches. Additionally, a study of the 13 volume Proceedings of the Interservice/Industry Training Systems Conference (I/ITSC) yielded some valuable information. Many technical reports, technical notes, and calling papers that are not found in the general literature were analyzed. Finally, an informal survey was conducted of researchers at IST, PM TRADE, NTSC, UCF, and simulation and training industries around the Central Florida Research Park area.

3.0 Report Organization

This report is comprised of a bibliography in American Psychological Association (APA) format, as well as an annotated bibliography citing the same sources, but including abstracts and additional comments for each reference. Each citation is preceded by an indicator of its topical content. The indicators are coded as follows:

- D - Transmission Delay
- F - Fidelity
- P - Performance Measurement & Training
- V - Visual Systems, including resolution, field-of-view, and target-background contrast

Preceding the source listings will be a summary of the literature findings regarding each of these four topics.

4.0 Summary of Findings

4.1 Transmission Delay

Some of the information surveyed indicated that there are smaller effects due to delay and that these effects tend to favor higher fidelity conditions. The Uliano et al.

(1986) study demonstrated that with varying amounts of asynchronous lags (215 ± 70 msec., 177 ± 23 msec., 126 ± 17 msec.), there are no differences between lag conditions with respect to the development of simulator sickness symptomatology, but that simulator performance is differentially affected by such lags, with the longest lag producing the worst performance. Another Uliano study (1991) found that although there were no significant delay effects, several trends emerged which could have serious training implications, namely that pilot strategy was altered as a result of delay conditions. In looking at 4 delay conditions - 0 msec, 250 msec, 500 msec, and 750 msec - and also at such variables as number of missiles fired, hit/miss ratio, number of gun and missile kills, subjective ratings by pilots, and advantageous or disadvantageous starting position, it was found that pilots in an advantageous position are less successful with each missile fired as the delay is increased, and therefore, in an effort to increase their hit/miss ratio, fire more missiles in hopes that one will hit. For those in the disadvantageous position, their hit/miss ratio is increased simply because they remain alive longer and have more of a fighting chance as delay increases. Additionally, it was found that as delay increased up to 500 msec, pilots rely less on their missiles and more on their guns, which are affected little, if any, by delay. These results are in contradiction to the fact that pilots did not perceive that their performance was being affected by the delay conditions.

Other studies indicate that even small delays can degrade performance and impose a workload penalty. They point to a 150 msec (or 0.15 sec) delay as the upper limit of tolerable delay in a simulation environment for level 1 (satisfactory) handling qualities in both the pitch and roll axes, as opposed to a 100 msec (or 0.10 sec) limit of the present specification (MIL-F-8785C) for both axes. This delay requirement reflects the most stringent condition of a highly maneuverable, highly responsive fighter aircraft simulation flown in a demanding task environment. The 150 msec requirement may be conservative and hence, relaxed for less responsive aircraft or vehicles flown in less demanding tasks. Study results also suggest a level 2 (acceptable but unsatisfactory) handling qualities limit for an effective time delay of 0.82 sec and 0.57 sec for the pitch and roll axes, respectively, as opposed to 0.20 sec of the present specifications for both axes. These studies are a contribution to the effort to set standards for lag time between simulators, which have been temporarily and arbitrarily set at 500 msec. Work is continuing on establishing formal standards for acceptable intersimulator transmission delays, since to date, only intrasimulator standards have been established.

The literature also points to the fact that the effects of time delay, introduced during ground-based simulation, should be similar in many respects to in-flight effects and that the effects of time delay in ground simulation are not independent of simulation device particulars such as visual scene content, field-of-view, motion system design, and motion-visual cue synchronization. Any specification for maximum allowable simulator time delay must accurately reflect the flying qualities effects as

well as the attendant issues of transfer of training and quantified pilot control behavior variations.

Finally, the literature evaluated several types of delay compensators, particularly those utilizing an Optimal Control Model, which is a closed-loop model requiring detailed definitions of the system to be controlled, the command or disturbance inputs to that system, and the displayed outputs available to the pilot for monitoring and control. The research indicated that all of the compensators used were found to provide an improvement in performance and workload over full-delay, no compensation results, but the best results were obtained for an OCM-based time domain compensator, which uses an analytic expression as a fixed lead predictor for closed-loop pilot/vehicle dynamics and which can be readily extended to multi-input, multi-input problems.

4.2 Fidelity

Most of the studies that investigated fidelity concluded that the relationship between fidelity and transfer of training is complex and non-linear. It is an illusive and ill-defined variable which appears to be interdependent upon many other factors. There are different types of fidelity which have been investigated. There is physical fidelity, which is the degree to which the simulator "looks like" the real thing; functional fidelity, which is how well it acts like the real thing; and psychological fidelity, which is how well it is perceived to train like the real thing. The need for functional fidelity is equal to or greater than that of physical fidelity. Low functional fidelity has been shown to be associated with longer problem solution and interresponse time. Temporal measures appear to be the most sensitive to fidelity manipulations. Studies have shown that, in at least some situations, a simple simulator of a relatively complex task will produce as much positive transfer to the real task as will a more elaborate simulator with greater fidelity. There is also an interaction effect between overtraining and simulator fidelity such that overtraining on a more complex simulator can result in dominance of simulator content-specific habits that would subsequently interfere with posttransfer performance. Many of the studies surveyed favor higher fidelity conditions. Both Hays & Singer (1989) and Lane (1991) discuss fidelity as a construct and focus on current and future applications of fidelity in training system design. Hays & Singer present a history of simulation research, and Lane evaluates fidelity as it relates to DIS (Distributed Interactive Simulation). Lane also introduces "fidelity anchoring", which is a systematic method for making decisions about fidelity requirements in DIS. Fidelity anchoring tries for the highest possible fidelity, realism, and validity for the entire simulation and then selectively omits or degrades those components that are not critical to achieve the intended goals of the simulation. Lane asserts that it is more sensible, and much cheaper, to build the simulation from the ground up by matching the characteristics of each component to a defined purpose or intended use of the simulation. Using this method, each fidelity decision is based on a specific requirement.

4.3 Performance Measurement & Training

These articles looked at the development of training strategies, mechanisms for the transfer of learning, and methods for evaluating crew coordination effectiveness. They also investigated various aspects of visual system performance and the resultant impact upon human operator behavior. For example, certain display variables such as object detail and density, topography and vertical development, and perceived weather conditions and threat environment appear to influence performance variables such as situational awareness, judgment of altitude, and task loading. Peripheral vision provided by wider field-of-view was found to positively impact low altitude flying skills. The optical flow information (or "ground rush") emanating from peripheral vision aided the pilots in judging altitude. Another study utilizing a field carrier landing task found that for carrier landings at least, there was no transfer advantage for those pilots trained with a wider field-of-view scene compared to those pilots trained with a lower cost narrow field-of-view scene. This same study also found no transfer advantage for pilots trained with a daytime high-detail scene compared to those trained with a lower cost nighttime low-detail scene. Transfer performance was also better for students who had 40 or 60 simulator trials than for those who had 20 simulator trials, and a segmented approach was found to be as effective or more effective than the more time-consuming straight-in or circling approaches.

Mission success was found to be significantly affected by situational awareness, task management, and team work. Studies of combat teams indicated that teamwork is behaviorally complex and evolves over time; that teamwork skills contribute to the relative success of teams; and that top-ranked teams display certain behavioral tendencies distinct from the lowest-ranked teams. The effects of stress associated with increased responsibility are discussed in these articles, as is the feasibility of utilizing non-pilots as subjects in certain experimental tasks such as ranking the effectiveness of the visual environment. The studies show that in these types of tasks, it is not only feasible to use non-pilots, but also that a contribution to the overall cost-effectiveness of simulator displays can be made by doing so.

Simulator performance was found to be adversely affected by transmission lags (with the longest lags producing the worst performance) and by simulator sickness symptomatology. The problem of when to stop training on a simulator was discussed with emphasis on the idea that overtraining on a simulator of greater fidelity will lead to greater transfer decrement. Training should stop soon after the operation of the mechanism is learned and before habits specific to the performance on the simulator are developed.

The literature also presented five models developed for the Optimization of Simulation-Based Training Systems (OSBATS). These models focus on the need for training, the priority of instructional features, and resource allocation (based on procurement, use, and cost constraints). Finally, the literature discussed embedded

training (ET) and its effective implementation as a factor of the following: policy; system availability for training; the technical feasibility of ET implementation; the effects of ET on system reliability, availability, and maintainability; the impact of ET on system manpower and personnel requirements; the need for training-specific interface hardware; safety; and cost-effectiveness.

4.4 Visual Systems

Some of the literature findings with respect to color, contrast, and resolution are as follows:

- 1) Color may be a very effective performance factor under some conditions, but it may be detrimental under others.
- 2) Composite colors are composed in perception by combining the scaled (or relative) brightness of each spectral component. This brightness scaling is largely restricted to interactions in the same spectral regions.
- 3) Recommendations for color usage and contrast relative to visual display terminals include: a) Colored symbols should differ from their colored backgrounds by a minimum of $100 \Delta E$ (CIE L^*u^*v) distances; b) For colored coding, all colors in a set should differ from one another by a minimum of $40 \Delta E$ (CIE L^*u^*v) distances; c) Luminance modulation should be equal to or greater than .5 or a contrast ratio of 3:1.
- 4) One source presented methods for calculating color differences from instrumentally measured color coordinates.
- 5) In one study which endeavored to determine the minimum color difference that must exist between a color symbol and its background for the symbol to be reliably recognized, it was found that when a color symbol and its background were only 0.01 CIE/UCS units apart, observers were not able to recognize the symbol. This was true for red, green, and blue areas of color space and for all luminance levels examined (from 11.85 to 127.25 cd/m^2). In terms of luminance values, when blue symbols are to be presented against a bluish background, the display luminance should be approximately 19 cd/m^2 . For red and green symbology against red and green backgrounds, the luminance should be about 56-58 cd/m^2 .
- 6) For uniform color appearance, the same nominal color should not differ by more than $15 \Delta E^*_{uv}$ units for any two separated locations on the screen, and by no more than $5 \Delta E^*_{uv}$ units for any two adjacent locations.

- 7) The character size of an isolated image is recommended to be at least 30 minutes of arc and preferably 45 minutes of arc.
- 8) Small images composed of colors from the blue-green region of the spectrum are very difficult to identify and discriminate. Colors that must be discriminated should differ by a minimum of $20 \Delta E_{uv}^*$ units and preferably $40 \Delta E_{uv}^*$ units from each other and their backgrounds. If large color contrast differences are required, image and background colors should differ by at least $80 \Delta E_{uv}^*$ units.
- 9) ISO 9241 Standard states that minimum luminance contrast of character details relevant for legibility should be $C_m=0.5$ (contrast modulation) or $CR=3:1$ (contrast ratio). Uniform luminance variation from the center of the display to its edge shall not exceed a ratio of 1.7:1 or 1.5:1 within a character.
- 10) Any use of color must take into account not only hue, but also saturation and luminance. Temporal and spatial variables and individual differences can affect color coding.
- 11) Basic discriminable colors include blue, red, yellow, green, orange, purple, black, white, and brown. Population stereotypes for color also need to be taken into account. Full-color displays are preferred by pilots (especially for head-down displays) and performance is superior when using full-color pictorial displays.
- 12) Field size can have an effect on color discrimination. Smaller fields require larger offsets for color discrimination.
- 13) For color discrimination, hues should be at least 0.032 UCS units apart.
- 14) In studies utilizing a signal detection paradigm with a symbol recognition task in order to determine how far apart, in CIE/UCS color space, symbol and background chromaticities need to be in order for observers to reliably recognize a symbol, it was found that a d' of 3.0 which is near perfect performance is related to symbol/background chromaticity differences of 0.06 units in the 1976 UCS color space.
- 15) Another study investigated the effects of vertical spatial resolution, pixel height, and display height on the visibility of straight vertical line signals in visual noise. A signal detection analysis of the results showed that detection efficiency is unaffected by vertical resolution and pixel height, whereas an increase in display/signal height resulted in a decline in efficiency. The decline is attributed to the increasing difficulty the visual system encounters when integrating luminance over an increasing spatial extent. It is suggested

that in practical digital displays, pixels should be as short as possible in order that the available display information be compressed into the smallest possible height.

- 16) Human contrast sensitivity is a function of spatial frequency; therefore the spatial frequency content of an image should be considered in the definition of contrast.

Investigation of other visual display variables led to the following conclusions:

- 17) Object density and detail, terrain or topography features, and vertical development were found to be effective cues in the perception of altitude. "Ground rush" (optical flow information or the distribution of environmental features) is also a potent cue for altitude perception. For three-dimensional objects, a density of about 12 to 15 objects per square mile is necessary and sufficient for maintaining altitude and orientation.
- 18) Peripheral vision, provided by wider field-of-view displays, is a primary source of optical flow information mentioned above. When field-of-view is limited, eye position data obtained revealed an increased use of front windows and instruments and decreased use of the window to the left of the pilot. Peripheral windows may not be required for experienced pilots, but if present, are used, and if absent, alter visual behavior. Wide field-of-view displays should be used when the training objectives include tasks that use a large amount of peripheral information.
- 19) The commonly-held belief that flight simulators should possess full field-of-view displays with high levels of brightness and resolution is complicated by the fact that these three factors are not independent. For example, as field-of-view increases, brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with instantaneous limited field-of-view sizes. These systems provide a full field of regard for the head-driven instantaneous field-of-view. Studies examining the effect of instantaneous field-of-view size on pilot performance yielded inconclusive results with the exception that the smallest stationary field-of-view condition (127 degrees horizontal X 36 degrees vertical) is judged unacceptable for performing pop-up weapons delivery. Experienced pilots require a minimum field-of-view of 160 degrees horizontal X 60 degrees vertical for pop-up weapons delivery tasks. In addition, head movement was found to be related to both field-of-view size and display type (stationary and head-driven). The pilots appear to place greater reliance on instruments in smaller field-of-view conditions.

- 20) Factors affected by field-of-view are depth, altitude, and motion. Pilot control strategy may also be impacted by the size and placement of the field-of-view. Additionally, there is often a trade-off between the amount of scene detail available and field-of-view size. The ideal, but not often feasible, situation is to provide the same visual area as available in the aircraft.
- 21) Subjective reports by pilots indicated a need for about 120 degrees horizontal vision, or visual field-of-view. Pilots also indicated that during formation flight, they need to see somewhat aft of the 3-9 line and to be able to check 6 for threat aircraft. For a full simulation of a daylight tactical mission, the instantaneous field-of-view should be 120 degrees and the display should have a full field of regard. A lesser capability display may suffice for a night mission.
- 22) No evident advantage for using a wide field-of-view for training straight-and-level flight was found.

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6.0 Annotated Bibliography

Alessi, S. M. (1988). Fidelity in the design of instructional simulations. Journal of Computer-Based Instruction, 15, 40-47.

F Simulation research places considerable emphasis on the variable of fidelity. While designers of mechanical simulators originally assumed increasing fidelity would enhance transfer of learning, research indicates a more complex, non-linear, relationship. Computer simulations, which are inherently lower in fidelity than mechanical simulators, are used to teach a wider variety of subject areas. The relationship of fidelity and learning in computer simulation has not been adequately researched. The nature of that relationship is discussed, including implications for instructional design and research.

Allen, G. A. (1989). Transferring simulation data between dissimilar computers in an Ada environment. Proceedings of the Eleventh Annual Interservice/Industry Training Systems Conference (pp. 414-421).

V In order to meet requirements for an Ada-based training system, a Silicon Graphics-based instructor's station was connected to a host Concurrent Computer Corporation main simulation computer complex via a smart shared-memory interface. The Silicon Graphics system performed all necessary processing required for the instructor's station and generated displays on the graphics CRT and flat panel displays. This paper describes techniques used to transfer data between the two dissimilar computers in an Ada environment. These techniques were incorporated into an Ada code generation program that generated the Ada code necessary to transfer simulation data between the two systems.

Allen, J. A., Hays, R. T., & Buffardi, L. C. (1986). Maintenance training simulator fidelity and individual differences in transfer of training. Human Factors, 28, 497-509.

- F This study was undertaken to investigate the relationship between simulator fidelity and training effectiveness. Two aspects of simulator fidelity were manipulated, namely, the degree to which a training simulator "looked like" actual equipment (physical fidelity), and the extent to which it "acted like" real equipment (functional fidelity). A transfer of training design was used to assess learning. Performance on an electromechanical troubleshooting task was correlated with a number of individual difference variables. Results indicated that physical and functional fidelity were interdependent and that temporal measures were most sensitive to fidelity manipulations. Low functional fidelity was associated with longer problem solution and inter-response times. Persons with high analytic abilities took longer to solve problems, but required fewer troubleshooting tests and made fewer incorrect solutions.

American National Standard for Human Factors Engineering of Visual Display Terminal Workstations, ANSI/HFS. (1988). Santa Monica: Human Factors Society, Inc.

- V Recommendations are presented for color usage and contrast relative to visual display terminals. The Standard recommends that for color contrast for adequate legibility, colored symbols should differ from their colored backgrounds by a minimum of 100 ΔE (CIE $Y u'v'$) distances, and for color coding all colors in a set should differ from one another by a minimum of 40 ΔE (CIE $L^*u^*v^*$) distances. In terms of luminance modulation the standard states that it shall be equal to or greater than 0.5 or a contrast ratio of 3:1.

Anstis, S., & Cavanagh, P. (1983). A minimum motion technique for judging equiluminance. In J. D. Mollon and L. T. Sharpe (Eds.), Colour vision. London: Academic Press, 155-166.

- V The authors evaluate a new technique for matching the luminance of different colors based on apparent motion. The new method exploits the advantages of TV systems over optical systems.

ASTM standards on color and appearance measurement. (1987). Philadelphia: ASTM. 2nd ed.

- V The methods for calculation of color differences from instrumentally measured color coordinates are presented. Measurements are based on daylight illumination of small color differences between nonfluorescent, nonmetameric, opaque specimens such as painted panels. The color differences determined by these procedures are expressed in approximately uniform color spaces of CIE

1976 CIELAB, Hunter LH, aH, bH, and the Friele-MacAdam-Chickering (FMC-2). This reference also provides a standard method of specifying color by the Munsell color system based on color-perception attributes.

Bailey, R. E., Knotts, L. H., Horowitz, S. J., & Malone, H. L., III. (1987).

Effect of time delay on annual flight control and flying qualities during in-flight and ground-based simulation. Proceedings of the American Institute of Aeronautics and Astronautics, Inc. 1987 Conference.

- D From flight testing research, 100 msec has been established in the military specification for piloted vehicle flying qualities (MIL-F-8785C) as the allowable maximum delay between cockpit control input and aircraft response for satisfactory Level 1 handling qualities. Level 2 and Level 3 upper limits were established at 200 and 250 msec delay, respectively....Time delay is not only a problem in flight control design, but also in ground-based simulation design....The effects of time delay, introduced during ground-based simulation, should be similar in many respects to the in-flight effects....The effects of time delay in ground simulation are not independent of simulation device particulars such as visual scene content, field-of-view, motion system design, and motion-visual cue synchronization....This paper describes the results of an experiment whose goals were the generation of guidelines and development of a data foundation for the specification of allowable time delay in ground-based simulators. The effects of time delay on flying qualities and manual flight control were investigated during in-flight simulation where "perfect" motion cuing is available. Because the in-flight simulator also had the capability to serve as a ground simulator cab, a ground-based, no-motion replication of the in-flight experiment was also performed. The experiment will permit investigation of simulator motion requirements by examining the extreme conditions of motion versus no-motion. The visual cues for both the ground and flight phases of this study were limited to a head-up display. This contrasts with previous in-flight investigations that used full field-of-view, "perfect" visual environments. Subsequent investigations can build from this foundation regarding the influences of ground simulation device particulars (e.g., visual scene fidelity, motion base washouts, etc.)....Three variables were tested: time delay; aircraft configuration (control response characteristics and mission); and motion cuing....The experiment matrix consisted of five values of pure time delay (added to the simulation) ranging from 0 to 240 msec. Delay was, of course, the primary experiment variable, and it was introduced to both the pitch and roll axes....The maximum tolerable delay introduced in a simulation can be defined as the maximum delay before which flying qualities degrade to Level 2 (given that Level 1 flying qualities existed without added delay)....A specification for maximum allowable simulator time delay must accurately reflect the flying qualities effects as well as the attendant issues of

transfer of training and quantified pilot control behavior variations....Given the results of this experiment, total delays of up to 150 msec (100 msec plus 50 msec experimental added delay) are tolerable in a simulation environment. This delay requirement reflects the most stringent condition of a highly maneuverable, highly responsive fighter aircraft simulation flown in a demanding task environment. The 150 msec requirement may be conservative and hence, relaxed for less responsive aircraft or vehicles flown in less demanding tasks. For this specification requirement, the total delay reflects the "equivalent" time delay from cockpit control input to visual system response. It should be noted that this delay specification arises from a complete, full fidelity non-attenuated motion simulation. The in-flight experiment was replicated using the N-33A as a ground simulator to investigate the effects of time delay when no motion cues are available. Significant flying qualities differences were shown to exist particularly for a highly responsive, aggressively flown aircraft. The effects of motion are least significant for a sluggish aircraft flown in a benign mission/task environment.

Baron, S., Lancraft, R., and Caglayan, A. (1982). An optimal control model approach to the design of compensators for simulator delay. Bolt Beranek and Newman Inc., Report No. 5004. Prepared for NASA-Ames Research Center.

D This report summarizes an analytical study of the effects of display delay on pilot performance and workload and of the design of filters to ameliorate these effects. The Optimal Control Model for pilot/vehicle analysis was used both to determine the potential delay effects and to design the compensators. The model was applied to a simple roll tracking task and to a complex hover task. The results confirm that even small delays can degrade performance and impose a workload penalty. A time-domain compensator designed by using the Optimal Control Model directly appears capable of providing extensive compensation for these effects even in multi-input, multi-output problems.

Additional comments from article: Recent references have suggested compensating for simulator delay by simple lead-lag filters. These compensators are designed to operate with a single input variable and have a single output; their design is best understood as a simplified single-loop system. This approach is essentially motivated by an attempt to approximate the pure lead, while filtering unwanted noise....An alternative approach to the design of the lead-lag compensator, based on classical, closed-loop control concepts, was proposed by Crane (1980). The basic idea is to pick the time constants to restore the closed-loop phase margin to that of the no-delay case. It is assumed that this will mitigate the need for the pilot to generate the added lead required because of the delay and, thereby, will help alleviate the performance and workload penalties normally accompanying the delay. The

result of a classical control system analysis leads to choosing the design parameters ...such that a) the filter zero is placed slightly beyond crossover; b) the filter pole is chosen so that filter lead cancels the phase lag at crossover due to the delay, and 3) the gain factor is chosen to yield unity gain at crossover....The OCM is a closed-loop model which requires a detailed definition of the system to be controlled, the command or disturbance inputs to that system, and the displayed outputs available to the pilot for monitoring and control....The OCM was used in the designing and evaluation of three delay compensators. The compensators were evaluated from a pilot-centered orientation; i.e., the design criteria were chosen so that the objective of compensation was to restore, as closely as possible, the pilot's response to that of the no-delay situation....The basic idea behind the OCM frequency domain compensator is to relieve the pilot of the necessity for generating the additional lead by approximating the incremental predictive response by the delay compensator. This is accomplished by computing pilot describing functions with and without system delay, calculating the "difference" between these two describing functions, and designing a filter to approximate that difference....Motivated by the difficulty in extending frequency domain compensators to multi-input, multi-output (MIMO) cases, a state-space (time-domain) compensator was developed. The basic idea behind the design of this compensator is to use the OCM to develop an analytic expression that can be used directly as a fixed lead predictor for the closed-loop pilot/vehicle dynamics....Based on the single-axis results of this study, the OCM time domain compensator was selected as the compensation scheme best able to replicate the desired no-display delay conditions...and may provide some possible reduction in overall workload. All the compensators used were found to provide an improvement in performance and workload over full-delay, no compensation results in the single axis task, but the best results were obtained for an OCM-based time domain compensator and, fortunately, this compensator is readily extended to multivariable problems. The time-domain compensator was also applied to the hover problem with extremely encouraging results.

Baum, D. R., Smith, D. A., Hirshfeld, S. F., Klein, G. A., Swezey, R. W., & Hays, R. T. (1982). Specification of training simulator fidelity: A research plan. (Technical Report No. 558). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences.

F This report presents a conceptual framework for identifying factors that may impact training simulator effectiveness. A research strategy is proposed for the empirical determination of necessary levels of training simulator fidelity. Preliminary studies consistent with this strategy are described to explore the

effects of device fidelity on the transfer of training of perceptual-motor and cognitive maintenance tasks.

Bell, P. C., & O'Keefe, R. M. (1987). Visual interactive simulation - history, recent developments, and major issues. Simulation, 49, 109-116.

V Visual Interactive Simulation (VIS) has dominated discrete-event simulation in the United Kingdom throughout the eighties. Conceived and initially implemented by Hurrion (1976), who also coined the phrase, VIS first gained widespread exposure through the package SEE-WHY. The ideas behind VIS are fundamentally different from what is referred to in the United States as animation, since the prime motivator is user interaction with the running simulation, rather than just portrayal of the simulation. After presenting a short history of VIS, we will discuss some of the research and development that has been undertaken in the United Kingdom and North America. Following presentation of an example, the state of VIS and a number of generally accepted guidelines for doing VIS are discussed. A number of recent developments, many of them also relevant to animation, and four major issues in the research and practice of VIS are presented.

Booth, G. R. (1988). Visual simulation for advanced fighter training. Proceedings of the Tenth Annual Interservice/Industry Training Systems Conference (pp. 108-114). Orlando, FL.

F,V This paper examines the background of fighter aircraft visual simulation, training requirements in support of realistic combat scenarios, present visual simulation capabilities and, for the future, advanced visual tactical training centers. Advances in Soviet weapons technology is increasing the threat to aircrew survival and mission success, thereby emphasizing the importance to train aircrews in a realistic combat environment. Unfortunately, combat related skills cannot be fully trained in the aircraft, due to limits of the training environment. These limitations include airspace, weather, safety, ordnance, and cost. The increased threat and limited peacetime training operations combine to place new and increasingly complex demands on today's tactical simulators. Currently, limited visual training capability exists for fighter aircraft simulators. However, today's technology is rapidly advancing to a state that future combat flight simulators will be equipped with visual, sensor, electro-optical and radar data bases, photographic in quality, that accurately replicate any location in the world. These simulators will be capable of providing mission scenarios that include all known threats, synergistic effects of electronic combat, and command and control. They will be located at

tactical training centers and will train combat skills to tactical aircrews realistically and effectively.

Additional comments from article: In summary, the major problem with TAF (Tactical Air Force) and current visual simulators has been the inability to produce bright, realistic (high res) image, over a full FOV....Currently, high cost visual systems are used primarily for research and development by aircraft manufacturers. With some technical improvements, they could be used as an advanced fighter visual system. Improvements would include: 1) full FOV (currently available); 2) multiship (linked visual systems) (currently available); 3) single visual, radar, sensor data base (currently under R & D (contractors' Project 2851)); 4) display systems with 1-arc minute (currently under R & D) and brightness of 10-ftL (currently available)....There is a requirement for advanced fighter training. Fidelity of present visual systems is poor compared with the real visual world. As the fidelity of the visual system increases, there is a corresponding increase in cost. To minimize the cost of procuring high fidelity visual systems for the TAF, I propose a single advanced Fighter Training Center should be constructed. The Center will provide the training necessary to give the TAF fighter pilots the "edge" anywhere in the world.

Boynton, R. M. (1979). Human color vision. New York: Holt, Rinehart, and Winston.

V The author provides an excellent review of the entire field of color vision in this book.

Bruce, R. C. (1987). Simulation fidelity: A rational process for its identification and implementation. Proceedings of the Ninth Annual Interservice/Industry Training Systems Conference (pp. 20-25).

F The degree of fidelity required in simulators to effectively transfer newly acquired skills between the classroom and the work world remains illusive and ill-defined during the front end analysis of system design. Frequently, fidelity specifications are inconsistent between the ultimate users of the system, the acquisition agency, and the contractor charged with the design and production of the final training system. Such a situation is not in the best interest of the student and is likely to produce a device insensitive to the directions provided by sound instructional and engineering analyses. This paper presents a technique for allowing individual training tasks to define specific degrees of simulator fidelity and then objectively tracking the task/fidelity relationship throughout the design, development, and testing phases.

Cannon-Bowers, J. A., Prince, C., Salas, E., Owens, J. M., Morgan, B. B., Jr., & Gonos, G. H. (1989). Determining aircrew coordination training effectiveness. Proceedings of the Eleventh Annual Interservice/Industry Training Systems Conference (pp. 128-136).

P Recognition of the need for aircrew coordination training has led to the development of a number of military and commercial aircrew coordination programs in recent years. The effectiveness of such programs is unclear, however, due to a general lack of training effectiveness data. The purpose of this paper is to present a set of guidelines and recommendations for evaluating aircrew coordination effectiveness in the military. The evaluation plan presented here is drawn from an effort by the Naval Training Systems Center to develop aircrew coordination training for Navy and Marine pilots. Drawing from past work in program evaluation, training effectiveness, and aircrew coordination, this evaluation plan has a number of distinguishing features, including a) multiple levels of evaluation criteria, b) pre-training assessment, c) recognition of evaluation needs throughout the design cycle, and d) outcome data that can be used for multiple purposes. Such a comprehensive evaluation approach is necessary to ensure that mission safety and effectiveness are increased, and training resources optimized.

Carter, R. C. (1982). A design tool for color displays. Proceedings of the Human Factors Society-26th Annual Meeting, 500.

V The author discusses a FORTRAN language computer program which provides for choosing high-contrast colors for CRT displays. The input required for the program is: (1) the number of colors desired; (2) the chromaticity coordinates of the CRT phosphors; (3) the luminance range of each phosphor; and (4) the number of equal luminance steps available from each phosphor. The output includes: (1) tristimulus values; (2) luminances on each phosphor; and (3) color contrast between all pairs of colors.

Christ, R. E. (1975). Review and analysis of color coding research for visual displays. Human Factors, 17, 542-570.

V The experimental literature on the effects of color on visual search and identification performance was reviewed. Forty-two studies published between 1952 and 1973 were located that gave results which could be used to determine the effectiveness of color codes relative to various types of achromatic codes. Quantitative analyses of these results indicated that color may be a very effective performance factor under some conditions, but that it can be detrimental under others. Tentative conclusions about the nature of these

conditions were derived from the results. A guide for design decisions and an indication of knowledge gaps are also provided.

Commission Internationale De L'Eclairage. (1978). Recommendations on uniform color spaces - color difference equations - psychometric color terms. Paris, France: CIE.

- V This report is based upon the recommendations prepared by Technical Committee No. 1.3 (TC 1.3) of the C.I.E. It essentially consists of formulas and terms used to determine the values in the CIELUV color space.

Crawford, R. L., Toms, M. L., & Wilson, D. L. (1991). Effects of display luminance on the recognition of color symbols on similar color backgrounds. Proceedings of the Human Factors Society-35th Annual Meeting, 1446-1470.

- V This study examined the effects of display luminance on an observer's ability to discriminate a color symbol on a similar color background using a Signal Detection paradigm. In the present study, background and symbol luminance were the same, with the only difference between the symbol and the background being chromaticity. The object was to determine the minimum color difference that must exist between a color symbol and its background for the symbol to be reliably recognized. The chromaticity distances employed were 0.01, 0.03, 0.05, and 0.07 units in 1976 CIE/UCS color space. Luminance units ranged from 11.85 to 127.25 cd/m². The results showed that when a color symbol and its background were only 0.01 CIE/UCS units apart, observers were not able to recognize the symbol. This was found to be true for the red, green, and blue areas of color space and for all luminance levels examined. In terms of luminance values, when blue symbols are to be presented against a bluish background, the display luminance should be approximately 19 cd/m². For red and green symbology against red and green backgrounds, the luminance should be about 56-58 cd/m².

Cream, B. W., Eggemeier, F. T., & Klein, G. A. (1978). A strategy for the development of training devices. Human Factors, 20, 145-158.

- F,P This paper discusses the complex issues involved in the design of aircrew simulation training devices. It addresses methods for defining training requirements, fidelity, performance measurement, instructional features, and crew coordination. A research evaluation of a device using these methods is presented.

Creutzfeldt, O., Lange-Malecki, B., & Dreyer, E. (1990). Chromatic induction and brightness contrast: a relativistic color model. Journal of the Optical Society of America, 7, 1644-1653.

V It has been suggested that object colors in a colored environment are the result of combining in perception the (relative) brightness of each spectral component rather than of just mixing the spectral luminances. We tested this hypothesis with the following experiment: A pair of center-surround targets made of colored papers was illuminated with trichromatic white light. Two identical central color plates (test and match field, respectively) were surrounded by frames of different colors and thus looked different because of simultaneous color contrast. Observers were asked to match the colors by changing the illumination of the match field by means of a color-mixture projector (color match, CM). This color-matched reflectance was measured with a photometer, and its CIE coordinates were determined. We then illuminated the display with one of the three primaries that made up our trichromatic white light. The different reflectances of the different surrounds at each primary induced simultaneous brightness contrast. The brightness of the two central plates were therefore different. Observers were asked to change the intensity of the illumination of the match field at the X,"dD primary so that it looked equally bright as the test field. This procedure was repeated for each primary (primary brightness match, PBM). Then the whole display except for the match field was illuminated with the trichromatic white as before, while the latter was illuminated with a trichromatic mixture consisting of the primaries at the intensities as set in the PBM experiment, and the CIE values were determined with the photometer. The CIE values of the match field after the CM and PBM procedures were nearly identical. This indicates that composite colors are composed in perception by combining the scaled (or relative) brightness of each spectral component and that this brightness scaling is largely restricted to interactions in the same spectral region. The results are compared with those of other models concerned with contrast colors as well as with neurophysiological data. Some limitations are mentioned.

De Corte, W. (1986). Optimal colors, phosphors, and illuminant characteristics for CRT displays: The algorithmic approach. Human Factors, 28, 39-47.

V The author presents a strategy for determining optimal colors, phosphors, and surround ambients for display, which is referred to as the COLSET algorithm. Pilot applications are discussed and guidelines for use are presented.

DeMaio, J., & Brooks, R. (1982). Assessment of simulator visual cueing effectiveness by psychophysical techniques. Proceedings of the Fourth Annual Interservice/Industry Training Systems Conference (pp. 379-381).

P,V Growing emphasis on simulation of low altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. However, such studies can be costly and time consuming, and often they provide equivocal results. The present study investigated the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cues provided by five visual system displays. Thirty Air Force pilots made estimates of the altitude above ground level (AGL) shown in slides of visual system displays varying in object density and object detail. Slides showed a 90 degree field-of-view scene taken in the F-16 cockpit of the Advanced Simulator for Pilot Training. Eight altitudes (range 50-400 ft. AGL) were presented for each visual scene condition. A random sequence of 40 slides (8 altitudes X 5 scenes) was presented three times. Power functions relating perceived to actual altitude were determined. Reliable differences were found between the displays which accorded well with differences found in a simulator flying study using the same display environments. Results are discussed in terms of display features and the measurement methodology.

Additional comments from article: The density of objects in the visual environment was found to be a potent, determining factor in the cueing effectiveness of visual displays. Object detail was found to be an important altitude cue. There was a suggestion of an interaction between object density and object detail in perception of altitude.

DeMaio, J., Rinalducci, E. J., Brooks, R., & Brunderman, J. (1983). Visual cueing effectiveness: Comparison of perception and flying performance. Proceedings of the Human Factors Society - 27th Annual Meeting, 928-932.

P,V Growing emphasis on simulation of low altitude and air-to-air tactical scenarios has greatly increased the requirement for simulator visual systems capable of providing the pilot high-fidelity out-of-the-cockpit cues. Evaluation of visual system performance through simulator flying studies has been the primary measure of system quality. Such studies can be costly and time consuming, and often they provide equivocal results. The present set of experiments was conducted to investigate the use of psychophysical measurement methodology to provide a quick, low-cost evaluation of the altitude cueing effectiveness of simulator visual displays. Experiment I examined altitude perception in several

visual environments. Experiment II was a validation effort, in which flying performance was evaluated in selected visual environments. In Experiment I pilots made altitude estimates based on static and dynamic presentations of visual displays containing texture and varying sizes of 3-dimensional objects. Best-fitting power functions were used to relate perceived altitude to actual altitude. In Experiment II Air Force pilots flew the Advanced Simulator for Pilot Training F-16 through five selected visual environments at 600 ft and 150 ft. AGL. Reliable differences were found as a function of display variables. In environments which provided strong altitude cues, pilots were able to fly very close to the designated altitude. In environments which provided poorer cues, pilots flew substantially above designated altitude.

Additional comments from article: 1) When an environment containing three-dimensional objects is evaluated, static presentation may be employed. Evaluation of the cueing effectiveness of two-dimensional texture requires a dynamic presentation mode. 2) A potent cue for altitude perception comes from the distribution, or flow, of environmental features. Perception of this information improves as the density of features in the visual environment increases. For three-dimensional objects a density of about 12 to 15 objects per square mile is necessary and sufficient for maintaining of altitude....3) A second aspect of visual cueing effectiveness was identified having to do with ground track control. This aspect of aircraft control involves initiation and control of turns. Visual cues required for ground track control are those which permit identification of roll-in and roll-out points. Unlike altitude cues, which must be uniformly distributed throughout the environment, ground track cues must be placed around particular decision points.

Dixon, K. W., Krueger, G. M., Rojas, V. A., & Martin, E. L. (1990). Visual behavior in the F-15 simulator for air-to-air Combat (Technical Report No. AFHRL-TP-89-75). Brooks AFB, TX: Air Force Human Resources Laboratory. (NTIS No. AD-A218 648/4/XAB)

V Flight simulators have evolved into complex systems capable of providing training for a number of operational tasks. These systems must make optimal use of the available technology to ensure cost and training effectiveness. Particular emphasis is placed on the requirements for field of view (FOV). The current research effort investigated the visual behavior of pilots performing air-to-air maneuvers in a F-15 simulator. The subject's eye position was recorded and window usage analyzed to determine what portion of the FOV the pilots used during the task and to obtain data on how pilots use their visual system during flight. The results infer that significant differences exist between window usage and task performed. In general, offensive set-ups displayed showed a greater usage of the front windows; defensive set-ups

displayed more usage of peripheral windows; neutral set-ups required little peripheral information; and the mutual support set-ups displayed a mix of all trends. The data from this effort can now serve as a baseline for more extensive investigations and comparisons between different aircraft, pilots, and experience levels.

Additional comments from article: In an experiment performed by Dixon, Martin, Rojas and Hubbard (1989)...eye position data revealed an increased use of the front windows and instruments in the limited FOV condition and a decreased use of the window to the left of the pilot. The authors concluded that the peripheral windows may not be required for experienced pilots, but if present, are used, and if absent, alter visual behavior.

Dixon, K. W., Martin, E. L., & Krueger, G. M. (1990). Effects of field-of-view sizes on pop-up weapons delivery (Technical Report No. AFHRL-TR-89-51). Brooks AFB, TX: Air Force Human Resources Laboratory. (NTIS No. AD-A223 018/3/XAB)

V It is commonly believed that flight simulators capable of supporting tactical combat tasks should possess full-field-of-view visual displays with high levels of brightness and resolution. The problem of designing such a visual system is that the three factors (field-of-view, brightness, resolution) are not independent. For instance, as field-of-view (FOV) is increased, brightness and resolution decrease. An attempt to overcome this dilemma uses head-driven visual displays with instantaneous limited-FOV sizes. Head-driven systems overcome the full-FOV problem by providing a full field of regard for the head-driven instantaneous FOV. Important considerations for head-driven instantaneous systems are the horizontal (H) and vertical (V) dimensions of the instantaneous FOV. The present research examines the effect of the instantaneous FOV size on pilots' ability to perform pop-up weapons deliveries using both stationary and head-driven visual displays. The FOV sizes investigated were 127 degrees H X 36 degrees V, 160 degrees H X 60 degrees V, 160 degrees H X 88 degrees V, and 180 degrees H X 88 degrees V. A 300 degrees H X 150 degrees V size provided a full-FOV control condition. An A-10 dodecahedron simulator configured with a 7-window color light valve display, computer-generated imagery, and a Polhemus magnetic head-tracker provided the cockpit and display apparatus. Aircraft performance measures (altitude, airspeed, etc.), head position data, and bomb miss distance were the dependent measures. Ten F-5 instructor pilots served as subjects for the experiment and flew all combinations of FOV sizes and display types from five initial points. The results did not confirm the initial hypothesis that performance would be better for head-driven conditions and larger fields-of-view. This may be due to an increased use of instruments in the

smaller FOV conditions to maintain performance levels. This conclusion is difficult to verify, because no eye position data are available. However, it is clear that the smallest condition (127 degrees X 36 degrees) is inadequate to support training of this task.

Additional comments from article: It was anticipated that performance differences would be found between display type (stationary and head-driven) and FOV size. Effects of field-of-view size were found more frequently than effects for display type for the FOV size by display type interaction....the significant differences associated with the root mean square of head movement in the smallest FOV condition indicate that head movement is related to both FOV size and display type. The authors believe that this finding suggests that pilots place greater reliance on instruments in conditions where appropriate out-of-the-cockpit visual information is not available....Overall, the results show that experienced pilots can quickly adapt to the various configurations and perform equally well whether or not the FOV is moving or stationary, except in the smallest stationary FOV condition....this FOV size (127 degrees H X 36 degrees V) is judged unacceptable for performing pop-up weapons delivery. The present results also suggest that the pop-up weapons delivery task can be performed by experienced pilots, using FOV sizes as small as 160 degrees H X 60 degrees V, without serious detriments to flightpath adherence or bomb scores. A further conclusion is that head-tracked FOV systems can be used in the performance of air-to-ground maneuvers.

Dixon, K. W., Martin, E. L., Rojas, V. A., & Hubbard, D. C. (1988). The effects of field-of-view on pilot performance in the C-130 WST. Proceedings of the Tenth Annual Interservice/Industry Training Systems Conference (pp. 362-371). Orlando, FL.

V In order to provide a cost effective simulator training environment, a number of variables must be optimized to meet training requirements with minimum cost. One such variable is the field-of-view (FOV) of the visual display. This study investigated the effect of field-of-view on pilot performance for low level flight and an airdrop in the C-130 weapon system trainer. The study was performed using two different field-of-view configurations. The conditions were wide field-of-view that used all six windows to provide a 160 degree H by 35 degree V visual field and a limited field-of-view that used the forward four windows to provide a 102 degree H by 35 degree V visual field from the left seat (pilot's). The tasks chosen by subject matter experts for the study were thought to be those most likely to require information from the peripheral windows. Automated pilot performance measures and eye position data were collected throughout the study. Twelve experienced C-130 pilots performed four trials over two different routes under both field-of-view conditions. The

pilot performance data showed no strong or consistent effects due to the field-of-view manipulation. The eye position data revealed an increased use of the front window and instruments in the limited field-of-view condition and a decreased use of the window to the left of the pilot. The study shows that the peripheral windows may not be required for experienced pilots, but if present are used, and if absent, alter visual behavior. Based on the results of the study, a preliminary conclusion would be to provide a wide FOV when the training objectives include tasks that use a large amount of peripheral information. Before any final conclusions can be reached regarding field-of-view requirements, the use of the windows from the copilot's position should be addressed, as well as the value for skill acquisition for less experienced pilots.

Additional comments from article: Factors affected by field-of-view are perceptions of depth, altitude, and motion. Pilot control strategy may also be impacted by the size and placement of the field-of-view. Additionally, there is often a trade-off between the amount of scene detail available and FOV size. The ideal situation is to provide the same visual area as available in the aircraft....The need for a forward window has been well established in previous research, but the need for peripheral windows is still a question of importance....Optical flow information from the periphery is thought to be an important factor in maintaining orientation.

Dixon, K. W., Rojas, V. A., Krueger, G. M., & Simcik, L. (1990). Eye tracking device for the measurement of flight performance in simulators (Technical Report No. AFHRL-TP-89-18). Brooks AFB, TX: Air Force Human Resources Laboratory.(NTIS No. AD-A220 075/6/XAB)

V This paper describes the use of an eye position monitor as a research tool for evaluating the field-of-view (FOV) requirements for simulator visual systems. Traditional evaluation methods rely on the use of pilot opinion and/or objective pilot performance measures. Neither provides a direct index of the pilot's visual behavior under alternative FOV conditions. Without a direct measure, interpretation of data is often problematic. The use of an eye position monitor provides a useful adjunct to these traditional methods. The present paper describes the system architecture, initial implementation, advantages and limitations, and future application.

Additional comments from article: Experimental efforts relying solely on simulator performance measures would have concluded that there were no differences between the two FOV conditions. However, the visual behavior differences indicate that pilots are altering their visual strategy to maintain performance parameters....The eye tracking system could also be used for

system design and evaluation. For instance, a quantitative evaluation of the visual cues used in low-level flight can be obtained with the eye tracking system. Such an evaluation will be extremely useful in order to optimize the scene content in visual displays. If incorporated into research and design methodologies, the eye tracking system could provide valuable information on the eye focal point for various tasks.

Durrett, H. J. (Ed.) (1987). Color and the computer. Boston: Academic Press.

- V This book is basically designed to bring together a collection of fundamental information on color, color displays, and color perception as it relates to color video displays and computer generated information. It includes a total of sixteen chapters with twenty-two contributors. Contributions cover the relationships between color displays and color science, human factors, perceptual color space, and a number of applications which include computer color displays in military cockpits, cartography, command, control, and communication systems, and network planning and design.

Eisner, A. E., Pokorny, J., & Burns, S. A. (1986). Chromaticity discrimination: effects of luminance contrast and spatial frequency. Journal of the Optical Society of America, 3, 916-920.

- V The effects of luminance contrast and spatial frequency on chromaticity discrimination of grating bars were examined in this study. Alternate bars of gratings were filled with light of a standard wavelength and light that could be varied in wavelength. The observer set the variable bars to match the standard bars in hue. Discrimination, as measured by the standard deviation of the matches, decreased as spatial frequency increased. Luminance contrast did not improve chromaticity discrimination but did lead to Bezold-Brucke hue shifts that were spatial-frequency dependent.

Gagne, R. M. (1954). Training devices and simulators: Some research issues. American Psychologist, 9, 95-107.

- P This paper described and clarified some research issues which occur in connection with the development, use, and evaluation of training devices. It indicated that training devices are utilized for two purposes: performance measurement and performance improvement. These two uses can be distinguished in the characteristics of the device which are essential for each purpose. When the device is used for performance measurement, the important characteristics are reliability and validity. When the device is used

for improving performance, the important characteristic is the amount of transfer of learning to an operational task. In either case, the degree of simulation becomes a secondary consideration. Research issues concerning these purposes include methodology, which encompasses job analysis, training, proficiency measurement, and criterion development. They also include theory, which encompasses structure of skills, the determinants of human variability, relationships of set and motivation to learning, and the mechanisms of transfer of learning.

Gehl, T. L., & Brann, J. J. (1990). Network requirements for distributed tactical training. Proceedings of the Twelfth Annual Interservice/Industry Training Systems Conference (pp. 80-87).

D,V The Department of Defense (DoD) has many individual and crew trainers that provide high-fidelity full- and part-task training for a specific element or subelement of its weapons system. With the exception of the Simulation Network (SIMNET) suite of tank trainers, most DoD trainers are not sufficiently interconnected to provide simulated battle environment tactical training. Recently, in workshops such as Standards for the Interoperability of Defense Simulations, the DoD emphasized the need for interoperable training systems across the Armed Services. To satisfy this demand, the DoD and industry are currently working together to develop a real-time network protocol standard that has major implications on the development of future training systems. Network simulation is an innovative and exciting solution to many training needs, which have a broad range of network requirements. The network requirements need to be specified for each training application to determine the implications of interoperable simulation. This paper will define some network requirements for tactical training. We will first discuss the user's needs that we determined from our involvement with the Naval Training Systems Center, the Project Manager of Training Devices, the Naval Oceans System Center, the Naval Sea Systems Command, the Integrated Systems Test, and the current standards process. From the user's needs, we will specify network requirements that address the issues of mediums, interfaces, bandwidths, costs, latencies, protocols, and expansion. Finally, we will discuss our experience of integrating commercial technologies, government standards, and university research into a network prototype to study the effects of network simulation.

Gilson, R. D., & Myler, H. R. (1991). Taxonomic transformations of visual media selections into display specifications. (Technical Report No. ARI-RN-91-36). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (NTIS No. AD-A235 596/4/XAB)

- V The primary research goal was a method for facilitating the design of visual display systems based on human visual capabilities and training needs. A taxonomic categorization scheme was developed which relates imaging requirements with capacities of the human visual system to obtain design descriptions. Categories were determined based on functional capabilities that define a visual system to engineers, e.g., update rates, pixel densities, refresh rates, and luminance capabilities. The chosen approach was to create a taxonomy based on a user query system and a tree structure of outcomes based on those choices. The philosophy is that only the user is knowledgeable about the specific task. With a structured flow of questions and answers the user would be guided into the best design given that specific task. An expert system illustrated an easy to use presentation format and provided an effective shell to hold the collected information. The basic idea in the use of this taxonomy is to specify an image, relate the image to visual functions, then translate the image specification into generic visual system characteristics, separate from current technology limitations. By specifying the imaging requirements and not the hardware, the taxonomy does not date itself. Gaps in knowledge were found and documented in the area of scene complexity, level of resolution required, and in the recommendation for field of view (FOV). Further research still needs to be conducted to address the thorny issue of how much resolution (fidelity) and the level of scene complexity are sufficient for specific training needs. An appropriate method is also needed for measuring and categorizing these two elements. No literature was found to substantiate the FOV recommendations. The recommendation of FOV is used for presentation detail, the specific training task, and audience size. Thus, FOV can be very different across applications and needs to be further addressed. From the instructional technology literature only general guidelines are available for generic training tasks. Instructional system design (ISD) is required still for each training application before any general taxonomic structure can be used. Thus, the taxonomic structure defined in this work is not a substitute for a sound ISD process. Rather it should complement the analysis of task specific imaging requirements. A taxonomy of imaging requirements will help instructional technologists communicate their visual requirements to design engineers. Further, the taxonomy provides a structure that focuses decisions about the relevant characteristics of the image presentation and not merely the means to that end, i.e., display system specifications.

Grantham, W. D., Smith, P. M., Person, L. H., Jr., Meyer, R. T., & Tingas, S. A. (1987). Piloted simulator study of allowable time delays in large-airplane response. NASA Technical Paper 2652.

D A piloted simulation was performed to determine the permissible time delay and phase shift in the flight control system of a specific large transport-type airplane. The study was conducted with a six-degree-of-freedom ground-based simulator and a math model similar to an advanced wide-body jet transport. Time delays in discrete and lagged form were incorporated into the longitudinal, lateral, and directional control systems of the airplane. Three experienced pilots flew simulated approaches and landings with random localizer and glide slope offsets during instrument tracking as their principal evaluation task. Results of the present study suggest a level 1 (satisfactory) handling qualities limit for an effective time delay of 0.15 sec in both the pitch and roll axes, as opposed to a 0.10 sec limit of the present specification (MIL-F-8785C) for both axes. Also, the present results suggest a level 2 (acceptable but unsatisfactory) handling qualities limit for an effective time delay of 0.82 sec and 0.57 sec for the pitch and roll axes, respectively, as opposed to 0.20 sec of the present specifications for both axes. In the area of phase shift between cockpit input and control surface deflection, the results of the present study, flown in turbulent air, suggest less severe phase shift limitations for the approach and landing task - approximately 50 degrees in pitch and 40 degrees in roll - as opposed to 15 degrees of the present specifications for both axes.

Harvey, E. P., & Schaffer, R. L. (1991). The capability of the distributed interactive simulation networking standard to support high fidelity aircraft simulation. Proceedings of the Thirteenth Annual Interservice/Industry Training Systems Conference (pp. 127-134).

D,V How will U.S. tactical aviation forces train for future conflict? The prevailing budgetary climate will force a reduction in the frequency of training operations using actual equipment for some time to come. One cost-effective means for U.S. combat forces to conduct training is through the application of distributed simulation technology. A large scale simulation network which is based on the new Distributed Interactive Simulation (DIS) draft military standard for simulator networking and is accessible by the components of all three services will be the likely medium for conduct of this type training. DIS networking protocols evolved from ground vehicle networking protocols developed during the U.S. Army/DARPA SIMNET program. It is therefore understandable that some misconceptions may exist over the capability of DIS to provide sufficiently accurate vehicle position and orientation data for high performance aircraft simulation. High performance tactical aircraft simulation requires a high degree of vehicle position and orientation accuracy for conduct of fully effective training. Operational community acceptance is dependent upon the capability of a DIS network to support all potential high performance aircraft combat interactions including air-to-air missile engagements and air-to-air

gunnery. This paper will quantitatively detail DIS vehicle position and orientation accuracies throughout the potential range of simulated aircraft maneuvering capability. Entity State (position/orientation) Protocol Data Unit (PDU) transmission frequencies for differing order Dead Reckoning (DR) algorithms will be empirically derived for the F-16 fighter aircraft performing the dynamic Paris airshow flight routine. Average Entity State PDU transmission frequencies will be presented as a function of dead reckoning algorithm threshold values. This data will show the capability of the DIS networking standard to support high fidelity aviation training tasks, even those requiring precise real-time position updates such as air-to-air gunnery, while achieving significant network bandwidth reductions.

Hays, R. T. (1981). Research issues in the determination of simulator fidelity: Proceedings of the ARI sponsored workshop 23-24 July, 1981. (Technical Report No. 547). Alexandria, VA: U.S. Army Research Institute for the Behavioral and Social Sciences. (NTIS No. AD-A118253)

F This report is the proceedings from an ARI sponsored workshop on "Research Issues in Simulator Fidelity." Papers are included which: 1) state the goals and organization of the workshop, 2) present topics which were addressed during the workshop, 3) summarize the efforts of the working/discussion groups, and 4) summarize the results of the workshop as a whole. Workshop topics included definitional issues, communications issues, research support issues and research methodology issues.

Hays, R. T., & Singer, M. J. (1989). Simulation fidelity in training systems design: Bridging the gap between reality and training. New York: Springer-Verlag.

F This book develops a theoretical, historical, and empirical framework on which training system design decisions may be based. The construct of fidelity is used to help specify the characteristics of training media. Problems with terms are outlined along with a history of the use of training devices in systems using fidelity as a training systems design concept. A selected review of the literature is also provided, and results of this research are used to provide suggestions for effective training systems design. More recent research efforts are also outlined which provides a somewhat more forward approach to training systems fidelity. Finally, a review of some of the current trends and future directions of fidelity in training systems development is provided. To our knowledge, this is the only reference source which attempts to provide a history of simulation research and utilization that sheds some light on the fidelity construct.

Heintzman, R. J., Brown, J. E., & Jones, R. B. (1991). Tactical mission training, Designing the visual system to pilot perceptual requirements. Proceedings of the Thirteenth Annual Interservice/Industry Training Systems Conference (pp. 549-555).

P,V To determine visual requirements for ground-based tactical trainers, it is necessary that system designers understand how the aircrew perceives the real world in a tactical situation including what and how various cues are used to accomplish the mission. Visual simulation system performance requirements are often based purely on visual perceptual data collected under laboratory conditions. Such data tends to overstate the requirement since it has no real world or training need modulation and does not reflect the effects of the aircraft and mission environment on human performance. It also does not address factors such as target obscuration or occulting nor how supplementary pointer cues and avionics may be used to locate a target. Data is also needed as to where a pilot looks within the field of view during each element of a mission in order to define field of view requirements of the display. It is important that the system designer understands the missions and likely conditions and environment that affect the pilot in the real world so that the simulation can reflect these conditions. He must also understand the cues used by the pilot to detect targets, waypoints, SAMS, etc., in order that the data base reflects the proper conditions and supporting cues. This paper briefly addresses the visual trade process, vision requirements, and the process of collecting and applying pilot perception data to support visual simulation requirements for tactical training in a USAFE type of environment.

Additional comments from article: Interview conclusions - Several of the same factors kept coming up in the discussions which seemed to have a large effect on mission success. Some of the most important were situational awareness, task management, and team work. Some of the external forces discussed which affect the performance of the mission are weather, topography, and the threat environment. Weather reduces situational awareness and increases task loading. It also can affect the flight plan, tactics, and the type and way in which the delivery is performed. Rough and rolling topography can also reduce situational awareness, increase task loading and affect the flight plan. Although flying in a very low altitude may improve survivability by helping avoid threats, it reduces situational awareness and makes task management more difficult. It also makes visual navigation and target identification more difficult. Whereas younger pilots sometimes seem to be able to express the way in which different problems are handled, it appears evident that experience and training made such problems much easier to deal with. It also appears that indepth pre-mission planning which anticipates and prepares the pilot to deal with many of the problems that may be encountered can greatly improve situational awareness once into the mission. Ground rush

in the peripheral is the most dependable cue to maintain altitude. However, all pilots indicated that they used vertical development such as trees, buildings, etc. where it exists. All pilots believed that peripheral vision was extremely important in flying low altitude. They felt that the ground rush came principally in peripheral vision. Several said that it seemed as though they needed about 120 degrees horizontal vision, or visual field-of-view. They also said that during formation flight, they need to see somewhat aft of the 3-9 line and to be able to check 6 for threat aircraft. Key concerns for any low altitude training should be to facilitate pilot survival ("avoiding the rocks") and accomplishment of the mission....Some of the more important conclusions reached with respect to the implications this data has on visual simulation for tactical mission trainers were as follow: 1) Avionics including INS/GPS, RADAR, and FLIR must provide the correct real world related cues to the pilot. These systems must closely correlate in content and position with the out-the-canopy visual; 2) Highly enriched ground information together with three dimensional objects are required to provide the pilot altitude cues for low altitude flight. Also, an instantaneous horizontal field of view of at least 120 degrees together with a full field of regard is required; 3) Since the pilots periodically make quick glances in the cockpit at low altitude, the visual display should be designed so as not to impair such glances; 4) A trainer visual system should be designed to provide controlled simulation of illusions. The trainer must also be designed so as not to inadvertently produce illusions which are not related to the real world; 5) For the full simulation of a daylight tactical mission, the instantaneous field of view of the display should at least be 120 degrees and the display should have preferably a full field of regard. A lesser capability display may suffice for a night mission. The visual system must include eye limiting resolution for formation and target aircraft detection and tracking. If necessary this may be done with target projectors; 6) The WSO has an important visual role in the F-15E. He must have visual display information of the formation aircraft, threats and the terrain. This could drive the overall display system design.

Hennessy, R. T., Lintern, F., & Collyer, S. C. (1981). Unconventional visual displays for flight training. (Contract No. N61339-78-C-0060). Orlando, FL: Naval Training Systems Center.

- V Use of simulators for flight instruction has typically followed the pattern of using similar instructional approaches to those that have traditionally been used for in-flight instruction. However, there is a growing awareness that a simulator permits radical departures from the traditional methods. Some of these may be less expensive or even more effective in terms of acquiring the skill. 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. Four different visual displays were evaluated for their effectiveness in the acquisition of flight tasks in a simulator. The control condition had a wide field-of-view, a horizon and a checkerboard ground plane that obeyed laws of motion and perspective. The experimental displays were: 1) a narrow field-of-view with horizon and checkerboard ground plane; 2) an outside viewpoint of an aircraft; and 3) a display that consisted only of normal flight instruments. Flight-naive subjects were taught to fly straight-and-level for twenty trials with either the control or one of the experimental displays and then tested for twenty trials on the control display. Training, transfer, and differential transfer performance was examined. Pre-training with the experimental displays resulted in substantial transfer savings to the control display. The differential transfer analyses did not show a clear advantage for any of the displays. The hypothesis that control skills can be learned using representations of the essential information that depart radically from the form found in natural scenes was supported by the results. The results also suggest that perceptual learning may occur quickly relative to control skill learning. Field-of-view did not importantly affect training or transfer performance of the Straight-and-Level task. In particular, there was no evident advantage of using a wide field-of-view for training this task. Unconventional visual displays show promise as cost effective means for teaching some flight skills. Research on optimizing visual displays for flight training need not be restricted to conventional out-of-cockpit scenes. It is possible that unconventional displays might prove to be superior to conventional displays on a time-to-train as well as a cost basis.

Hess, R. A., & Hildreth, B. L. (1990). Numerical identification & estimation: An efficient method for improving simulation fidelity. Proceedings of the Twelfth Annual Interservice/Industry Training Systems Conference (pp. 123-129).

F The total quality of simulation environments, measured in terms of realism, is largely a function of the fidelity of the mathematical models incorporated within the simulation. Modern aircraft simulations, especially high performance military aircraft, are extremely complex. As such, it is difficult to improve their fidelity. Modern numerical schemes for systems identification and parameter estimation provide simulation scientists and engineers a productive method for improving simulation fidelity. Such techniques are capable of extracting accurate mathematical models of aircraft from flight data with much greater efficiency than can be realized using conventional analysis schemes (such as analogue matching). Numerical identification and estimation (I & E) techniques are not only excellent means for developing aircraft aerodynamic models and propulsion models, but I & E techniques are nearly essential for insuring the quality of verification and validation (V & V) data

collected during flight testing. This paper discusses the application of numerical I & E techniques to math model fidelity improvement.

Hess, R. A., & Malsbury, T. (1991). Closed-loop assessment of flight simulator fidelity. Journal of Guidance, Control, and Dynamics, 14, 191-197.

F An analytical methodology is presented for the preliminary assessment of piloted flight simulator fidelity. The hypothesis that forms the central theme of the methodology is that many major simulator fidelity problems stem from simulator limitations that adversely affect the pilot's innermost feedback control loop, referred to here as the "primary control loop." This loop is the most critical in terms of task performance and the pilot's evaluation of vehicle handling qualities. The proposed methodology, based on a pilot/vehicle analysis of the vehicle and tasks being simulated, has the potential for serving as a tool for the rapid diagnosis of simulator fidelity problems. Selected results from experiments involving both flight test and piloted simulation of a UH-60A rotorcraft in a pair of demanding vertical and lateral hover tasks are used to exercise the methodology and indicate its potential.

Hofer, R. (1987). Training systems R & D program: Progress & challenges. Proceedings of the Ninth Annual Interservice/Industry Training Systems Conference (pp.32-40).

F,P The training device and simulation community has achieved the technological power to simulate military systems and operations with impressive realism. This technological strength is offset by the fact that we do not always consider the cost and potential training benefits of alternative approaches and the training effectiveness of the training systems that we field. This paper describes a joint R & D program between the Army Research Institute (ARI) and the Program Manager for Training Devices (PM TRADE) to provide training developers and engineers a set of tools to establish the capability for evaluating training alternatives with respect to: 1) desired effectiveness at minimum cost, or 2) maximum effectiveness at a given cost. We are developing computerized decision aids with supporting databases and procedures to help optimize the training development process. The program upon which we have embarked addresses: 1) the implications of MANPRINT for developing simulator/device based training systems; 2) the analysis of training requirements to determine skills and knowledge to be trained; 3) the development of training strategies; 4) the question of how much simulation or fidelity is enough given that a training device or simulator is needed; and 5) the best manner of implementing embedded training. We are also examining

optimal ways to organize and present the information needed for embedded training and electronically presented technical information.

Additional comments from article: Models for the Optimization of Simulation-Based Training Systems - At present, the OSBATS effort consists of five models. These are: 1) A Simulation Configuration Module that clusters tasks to be trained according to their need for training on a full mission simulator (FMS), one or more part-mission simulators (PMS), or actual equipment (AE); 2) An Instructional Feature Module that determines the relative priority with which instructional features should be included in a training device; 3) A Fidelity Optimization Module that determines the relative priority of features that allow a training device to represent aspects of the operational environment; 4) A Training Device Selection Module that selects the training devices that can be used to meet the training requirements for each task at the least cost; 5) A Resource Allocation Module that determines the optimal allocation of training time to training devices and actual equipment to meet all training requirements, considering constraints on device procurement and use.

Humphrey, T., & Winters, M. (1990). Definition and validation of the flying qualities and performance test criteria for the modern operation flight trainer. Proceedings of the Twelfth Annual Interservice/Industry Training Systems Conference (pp. 130-135).

F,V Modern flight training devices often require performance validation against actual aircraft flight test data to help produce realistic performance and handling qualities. Prior to performing the trainer validation task, a significant analysis and manipulation effort is required to develop the flight test data into a complete and consistent set of test criteria. By performing this comprehensive data analysis early in the program development, flight modeling validation problems can be identified, minimizing the risk of cost and schedule overruns. This paper addresses the data analysis and development process performed on a modern helicopter flight trainer (AH-1W) using the data analysis and development process performed on a modern helicopter flight trainer (AH-1W) using off-line software analysis tools, simulation modeling feedback, and extensive customer interaction. Off-line software tools are used to rapidly and efficiently perform such tasks as identifying and resolving discrepancies in the test data base, performing polynomial curve fits and data extrapolations, normalizing similar data sets, and graphically comparing data acquired from different maneuvers and from different aircraft. The paper addresses how the trainer flight simulation model can be used to adjust or establish trends in the data or to resolve conflicts between similar data sets from different sources. The necessity of extensive customer involvement in this iterative test criteria

definition process is stressed. The discussion concludes with specific recommendations on the data acquisition and analysis process, based on lessons learned, including the application of trainer specification tolerances.

ISO Proposed Committee Draft Standard. (1991). ISO 9241/Part 8, Ergonomic requirements for office work with visual display terminals (VDTs)-Part 8: Requirements for displayed colors. 24 Pages

- V The stated purpose of this part of ISO 9241 "is to prescribe basic specifications for computer display colors in order to optimize their visibility, identification, and discriminability", and is intended to be used complementary to ISO 9241, Part 3. Appendices include Colour Difference Calculation and Comparative Performance Test Methods. The visual performance objectives of the standard recommend that the "colours of images shall be detectable, identifiable, and discriminable from other colours in the display visual field." While it is acknowledged that no satisfactory color difference metric exists, the ISO 9241 Standard goes on to suggest that the CIE $L^*u^*v^*$ and ΔE^*_{uv} color difference parameter are suggested as being used to derive an approximate estimate. The metric is described as inadequate for computer display as it assumes large (2 degree or word-size) visual stimuli. Single characters, lines, symbols, or small targets may not be as discriminable as the metric predicts. It is recommended that for uniform color appearance, the same nominal color should not differ by more than 15 ΔE^*_{uv} units for any two separated locations on the screen, and by no more than 5 ΔE^*_{uv} units for any two adjacent locations. The character size of an isolated image is recommended to be at least 30 minutes of arc and preferably 45 minutes of arc. It was noted that small images composed of colors from the blue-green region of the spectrum are very difficult to identify and discriminate due to foveal small-field tritanopia. Colors that must be discriminated should differ by a minimum of 20 ΔE^*_{uv} units and preferably 40 ΔE^*_{uv} from each other and their backgrounds. If large color contrast differences are required for special applications, image and background colors should differ by at least 80 ΔE^*_{uv} . Colored displays will comply with ISO 9241, Part 3 for legibility which is based on luminance contrast.

ISO Proposed Committee Draft Standard. (1991). Visual display terminals (VDTs) used for office tasks. Ergonomic requirements-Part 3: Visual displays. Final Text. Document Number ISO 9241 Part 3: Visual displays. 47 Pages.

- V The ISO 9241 Standard states that the minimum luminance contrast of character details relevant for legibility shall be $C_m = 0.5$ (contrast modulation) or $CR = 3:1$ (contrast ratio). Uniform luminance variation from the center of

the display to its edge shall not exceed a ratio of 1.7:1 or 1.5:1 within a character. Other design requirements and recommendations and measurement conditions and conventions are also given. The Appendix also includes analytical techniques for predicting screen flicker, an empirical method for assessing temporal and spatial instability on screen, and a user performance test method including an assessment of discomfort.

Jones, E. R., & Hennessy, R. T. (Eds.) (1985). Human factors aspects of simulation. Washington, DC: National Academy Press.

F,P This book is a collection of simulation and training topics from the National Research Council's Committee on Human Factors. Contributors to the book consist of internationally recognized experts in the field of human factors implications of simulation technologies. The book, published in 1985, outlines the contributions of the behavioral sciences to simulation, and addresses specific research issues and future trends in simulation. The working group provided eight conclusions and recommendations that have served to remind researchers of the challenges faced by simulation and training researchers. These conclusions and recommendations include:

- (1). Physical correspondence of simulation [physical fidelity] is overemphasized for many purposes, especially training.
- (2). Simulators are often not used properly.
- (3). Simulation could be more cost-effective.
- (4). The role of behavioral science and human factors engineering in simulation is neglected.
- (5). Many persistent simulation problems are common across types and uses.
- (6). Our capability to measure operator performance is limited.
- (7). The use of modeling in simulation is not well-developed.
- (8). Science and technology of simulation are not well-developed or integrated.

Kottas, B. L., & Bessemer, D. W. (1979). Some crucial problems in training tank gunnery skills. Proceedings of the First Annual Interservice/Industry Training Systems Conference (pp. 193-200).

P Instructional systems development presents many problems for tasks that can be accomplished a variety of ways, and particularly for tasks containing unobservable processes. While unobservable processes are often ignored in instructional systems development, the way in which they are performed can have significant impact on operational performance. Evaluation of a tank gunnery trainer emphasized that considering only observable measures of performance when training gunners to engage moving targets was insufficient. The operational performance in getting a moving target depends critically on the amount of lead applied. The correct amount of lead, in turn, depends on the target speed. There are, however, several different (unobservable) cognitive strategies for determining lead based on target speed. The current research demonstrates that the cognitive strategy selected for training will have a marked impact on operational performance, and that selection of a strategy to be trained rests on an understanding of underlying psychological processes.

Lane, N. E. (1991). Fidelity and validity in distributed interactive simulation: Questions and answers (IDA Technical Note). Alexandria, VA: Institute for Defense Analysis.

F This talking paper provides insights into the construct of simulator fidelity as it relates to Distributed Interactive Simulation (DIS). The author addresses the fidelity issues in a unique question-and-answer format. The questions and answers outline current and future characteristics of DIS, and cover some basic definitions and terminology, particularly the problems associated with "fidelity" as an imprecise and not-very-useful term for talking about simulations. Distinctions between basic skills and warfighting skills are made, and the importance of these differences for DIS applications is underscored. Some basic issues in fidelity and its companion term "validity" are reviewed as they apply to simulations. Four key dimensions or "drivers" of fidelity requirements are identified, and their interactions examined. Based on these drivers, a systematic method for making decisions about fidelity requirements in DIS, called "fidelity anchoring", is introduced and some advantages discussed. To illustrate the broad potential of DIS, a variety of possible classes of applications are suggested, and the differing fidelity requirements of each class are analyzed.

Legge, G. E., & Kersten, D. (1987). Contrast discrimination in peripheral vision. Journal of the Optical Society of America, 4, 1594-1598.

V Contrast discrimination provides a psychophysical method for studying contrast coding in vision. Our purpose was to compare properties of contrast discrimination in central and peripheral vision. We used forced-choice procedures to measure contrast-increment thresholds as a function of pedestal contrast. Our stimuli were 2-cycle/deg Gaussian-windowed sine-wave grating patches. They were centered at retinal loci ranging from 10 degrees nasal to 20 degrees temporal on the horizontal meridian. At each eccentricity, curves relating increment threshold to pedestal contrast had the same shape. When increment thresholds and pedestal contrasts were both normalized by the contrast thresholds at the retinal eccentricity in question, the curves became superimposed and fell along the same dipper-shaped contrast-discrimination function. We conclude that, after scaling by the local contrast sensitivity, properties of the contrast discrimination are qualitatively and quantitatively similar from 0 degrees to 20 degrees on the retina. These findings suggest that mechanisms of contrast coding are similar in central and peripheral vision.

McFarland, R. E. (1988). Transport delay compensation for computer-generated imagery systems. NASA Technical Memorandum 100084. NASA Ames Research Center.

D In the problem of pure transport delay in a low-pass system, a trade-off exists with respect to performance within and beyond a frequency bandwidth. When activity beyond the band is attenuated because of other considerations, this trade-off may be used to improve the performance within the band. Specifically, transport delay in computer-generated imagery systems is reduced to a manageable problem by recognizing frequency limits in vehicle activity and manual-control capacity. Based upon these limits, a compensation algorithm has been developed for use in aircraft simulation at NASA Ames Research Center. For direct measurement of transport delays, a beam-splitter experiment is presented that accounts for the complete flight simulation environment. Values determined by this experiment are appropriate for use in the compensation algorithm. The algorithm extends the bandwidth of high-frequency flight simulation to well beyond that of normal pilot inputs. Within this bandwidth, the visual scene presentation manifests negligible gain distortion and phase lag. After a year of utilization, two minor exceptions to universal simulation applicability have been identified and subsequently resolved.

McIntyre, R. M., Morgan, B. B., Jr., Salas, E., & Glickman, A. S. (1988). Teamwork from team training: New evidence for the development of teamwork skills during operational training. Proceedings of the Tenth Annual Interservice/Industry Training Systems Conference (pp. 21-27).

P This study was a part of the program of cooperative research on team development and maturation involving the Center for Applied Psychology Studies of Old Dominion University and the Naval Training Systems Center, Orlando, Florida. In an effort to understand the specific behavioral components comprising teamwork, 11 Combat Information Center teams in an Anti-Submarine Warfare School, ranked according to an independent final exam score, were observed over a week training period. Team instructors served as the source of critical behavior data that were collected and analyzed. Results of the behavioral analysis indicate that teamwork is behaviorally complex and evolves over time; that teamwork skills contribute to the relative success of teams; and that top-ranked teams display certain behavioral tendencies distinct from the lowest-ranked teams. A sampling of the lessons learned from this research and recommendations for interventions to improve team performance and training are presented and discussed.

Miles, K. W. (1991). A generic model for rapid estimation of CBT development time. Proceedings of the Thirteenth Annual Interservice/Industry Training Systems Conference (pp.381-389).

V A review of the literature on the amount of time it takes to develop an hour of computer based training (CBT) reveals that figures range from less than 50 hours of development per hour to over 800 hours of development per hour of CBT instruction. An Instructional Systems Design (ISD) model is presented and related to a CBT development estimation model to provide a framework for the discussion of rapid estimation of CBT development time. The estimation model discusses some of the variables that affect development time and offers a method of estimating CBT development time using a simple JOB AID (included) that can be modified to meet local conditions and parameters.

Morriss, R. H., & Dunlap, W. P. (1987). Influence of value on spatial balance of color pairs. Journal of General Psychology, 114, 353-361.

V The spatial balance of the component colors is an important element of color harmony in a design. Munsell (1905) suggested that the area of each color in a composition be inversely proportional to the product of the color's 45D and value. Moon and Spencer (1944) proposed that both D and value contribute to spatial balance, but the dominant factor is the contrast of a color with the background or with the adaptation point of the eye. The purpose of the present study was to investigate the predictive power of these two rules for hues of equal D, varying in value. The stimuli were presented on three different achromatic backgrounds, and both complementary and adjacent pairs of hues were used. When two colors differed in value, subjects tended to avoid equal

areas. With black or white backgrounds subjects seemed to prefer larger areas of the color whose value was nearer that of the background, but with a gray background, their choice was either a narrow band of light or of dark color. These findings fail to support either the Munsell or the Moon and Spencer models.

Moulden, B., & Kingdom, F. (1987). Effect of pixel height, display height, and vertical resolution on the detection of a simple vertical line signal in visual noise. Human Factors, 29, 433-445.

V Spatial resolution is one of the parameters that engineers designing digital displays must consider. Three experiments are described that investigate the effects of vertical spatial resolution and the interrelated parameters, pixel height and display height, on the visibility of straight vertical line signals in visual noise. A signal detection analysis of the results showed that detection efficiency was unaffected by vertical resolution and pixel height, whereas an increase in display/signal height resulted in a decline in efficiency. The decline is attributed to the increasing difficulty the visual system encounters when integrating luminance over an increasing spatial extent. It is suggested that in practical digital displays of the kind described here, pixels should be as short as possible in order that the available display information be compressed into the smallest possible height.

Patterson, M. J., & Rinalducci, E. J. (1984). The effects of aerial perspective on altitude estimation. Proceedings of the Human Factors Society - 28th Annual Meeting, 542-544.

V Recent interest in the importance of visual displays within specified flight simulations and scenarios has led to increased emphasis on the identification of pertinent cues within these displays. Through the identification of these cues and their usage in altitude estimation, more effective simulation and hence training programs can be developed. The present explanatory study investigated the use of a psychophysical methodology in the evaluation of aerial perspective as a possible cue in altitude estimation. Specifically the effects of two levels of aerial perspective (present and reduced) and flight experience on estimations were examined. Based on the linear functions of log estimated vs. log actual altitude, differences were found between levels of flight experience in the aerial perspective-present condition. Subjective responses suggest that individuals are aware of the presence/absence of haze conditions and this information influences their altitude estimations.

Peli, E. (1990). Contrast in complex images. Journal of the Optical Society of America, 7, 2032-2040.

V The physical contrast of simple images such as sinusoidal gratings or a single patch of light on a uniform background is well defined and agrees with the perceived contrast, but this is not so for complex images. Most definitions assign a single contrast value to the whole image, but perceived contrast may vary greatly across the image. Human contrast sensitivity is a function of spatial frequency; therefore the spatial frequency content of an image should be considered in the definition of contrast. In this paper a definition of local band-limited contrast in images is proposed that assigns a contrast value to every point in the image as a function of the spatial frequency band. For each frequency band, the contrast is defined as the ratio of the bandpass-filtered image at that frequency to the low-pass image filtered to an octave below the same frequency (local luminance mean). This definition raises important implications regarding the perception of contrast in complex images and is helpful in understanding the effects of image-processing algorithms on the perceived contrast. A pyramidal image-contrast structure based on this definition is useful in simulating nonlinear, threshold characteristics of spatial vision in both normal observers and the visually impaired.

Post, D. L., & Calhoun, C. S. (1987). An evaluation of methods for producing specific colors on CRTs. Proceedings of the Human Factors Society-31st Annual Meeting, 1276-1280.

V Three experiments were performed to evaluate several models for generating colors having specific CIE chromaticity coordinates and luminances on a CRT. In general, seven predictive models were compared. These models usually assume that CRT guns do not interact and to some extent are invariant. The authors found that if approximations are adequate then the piecewise linear interpolation assuming constant chromaticity coordinates (PLCC) is fairly accurate and easy to implement. If maximum predictive accuracy is required the piecewise linear interpolation assuming variable chromaticity coordinates (PLVC) is the best. In general, however, it should be noted that no computational model is known to consistently yield high predictive accuracy.

Post, D. L., Costanza, E. B., & Lippert, T. M. (1982). Expressions of color contrast as equivalent achromatic contrast. Proceedings of the Human Factors Society-25th Annual Meeting, 581-585.

V Two experiments were conducted to examine and compare the relationships between color contrast, as represented by three uniform color spaces, and

achromatic contrast. The three uniform spaces were the 1976 CIE $L^*u^*v^*$, 1976 CIE $L^*a^*b^*$, and Cohen and Friden's 1976 Wab. These are all transformations of the 1931 CIE tristimulus space. The results suggested that a satisfactory transformation can be derived, but additional research will be needed.

Post, D. L., & Greene, F. A. (1985). Color naming as a function of stimulus luminance, angular subtense, and practice. Proceedings of the Human Factors Society-29th Annual Meeting, 1070-1074.

V This study examined the color names used by Americans for colors generated on a CRT. The stimuli consisted of solid circles subtending 2 degrees or 2 minutes of arc and were presented against a dark background. All colors were calibrated and adjusted to a tolerance of 5% luminance and 0.005 distance-units on the UCS diagram. This study analyzed color-naming behavior in three ways. First, it examined the stability of responding to specific stimuli and showed that this stability was affected mainly by chromaticity with some interaction with luminance. Second, individual subjects' vocabulary sizes and their consistency using the vocabularies were examined. Third, the probability of obtaining specific names were plotted as a function of chromaticity, luminance, and subtense. The authors demonstrated that probabilistic color-name boundaries can be derived here and that these boundaries change as a function of luminance and subtense.

Post, D. L., Lippert, T. M., & Snyder, H. L. (1983). Color contrast metrics for head-up displays. Proceedings of the Human Factors Society-27th Annual Meeting, 933- 937.

V This study attempted to relate distance in several color spaces to response speeds for reading colored numerals superimposed upon colored backgrounds. Three uniform spaces were selected for comparison with the 1931 CIE tristimulus space (Tri). These included the 1976 CIE $L^*u^*v^*$ (Luv), the 1976 CIE $L^*a^*b^*$ (Lab), and Cohen and Friden's (1976) Wab. The author found no consistent advantage to using any one of the uniform color spaces as they are presently defined, when compared to the 1931 tristimulus space. However, the author suggests that an advantage may result with a rescaling of the Luv and Lab spaces.

Rinalducci, E. J. (1981). Visual cues in the simulation of low-level flight (Contract No. F49620-79-C-0038). Final Report, USAF - SCEEE Summer Faculty

Research Program. Williams AFB, AZ: Air Force Human Resources Laboratory.

- V Visual cues used by pilots to maintain altitude in low level flight simulation were examined. In particular, terrain texture in the form of black vs. white topped inverted cones, the presence or absence of vertical development, and the effects of rate of motion on terrain features were investigated using pilots who varied in flying experience. Less experienced pilots demonstrated increases in their mean altitude and RMS deviation with an increase in airspeed or with an increase in airspeed combined with a lack of vertical development in terrain features. Experienced pilots, on the other hand, only showed increases in mean altitude and RMS deviation with an increase in airspeed. No differences were found between all black and white topped cones. Suggestions are made for application of research findings to CIG development and pilot training.

Additional comments from article: Depth perception has obvious relevance to visual flight simulation and the maintenance of altitude in flight. Outside the primary cue of retinal disparity there are the secondary cues of aerial perspective, linear perspective, retinal image and familiar size, texture gradient, motion parallax, streaming, interposition or overlay, height of an object in the visual field, light and shadow, as well as the physiological cues of accommodation and convergence. With regard to flight simulation some of these and related cues are more important than others, especially when viewing a dynamic scene....Recent reports cite texture as a very important terrain feature in the dynamic simulator or flight environment and in the maintenance of low level flight. Unique terrain features and surface detail enables a pilot to keep track of his position and estimate altitude. Closely related to texture would be motion through the visual environment as influenced by airspeed. Motion would particularly effect the cues of motion parallax and streaming in actual flight and motion parallax in simulated flight....Vertical development of terrain features is very important in the maintenance of altitude in low level flight simulation. This is particularly true for higher airspeeds (540 vs 300 KIAS). In addition, the use of vertically developed terrain features may be more important for less experienced pilots in maintaining altitude than for those with more experience. Thus, it would be more important to the less experienced pilot to have vertically developed terrain features in the CIG of the flight simulator.

Rinalducci, E. J. (1983). Visual cues in the simulation of low-level flight (AFOSR Grant No. 82-0144). Bolling AFB, DC: Air Force Office of Scientific Research/NL.

P,V The research described in this report was directed towards an examination of visual cues used by pilots to maintain altitude in low level flight simulation. The first study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail, density, and vertical development. Both pilot and non-pilot observers were employed. Differences between pilots and non-pilots existed for the accuracy of altitude estimation, but the rankings of the effectiveness of the visual environments were the same for both groups. These results indicate that the use of non-pilot subjects can contribute to the overall cost-effectiveness and development of future simulator displays. A second study examined three visual display environments using different display modes (including static and dynamic). Both pilot and non-pilot subjects were employed. Again, differences between pilot and non-pilot subjects were obtained for the accuracy of altitude estimation with the former being more accurate. Although the results were complex, both pilots and non-pilots showed, in general, an improvement in altitude estimation with the dynamic vs. the static mode of presentation and with increasing complexity scene. The results of both studies have relevance to the development of CIG and the evaluation of simulator visual environments.

Rinalducci, E. J., DeMaio, J., Patterson, M. J., & Brooks, R. (1983).

Psychophysical assessment of simulator visual displays. Proceedings of the Second Symposium on Aviation Psychology, 489-494.

P,V The present study investigated the use of a psychophysical technique to provide a quick, low-cost evaluation of altitude cues provided by five visual display system conditions in which terrain features were varied in detail and density. Both pilot and non-pilot subjects were employed. Differences between pilots and non-pilots existed for the accuracy of altitude estimation, but the rankings of the effectiveness of the visual environments were the same for both groups. These results indicate that the use of non-pilot subjects can contribute to the overall cost-effectiveness and development of future simulator displays.

Additional comments from article: In terms of terrain features, object density and object detail (particularly in the form of vertical development) appear to be important cues for altitude estimation.

Rinalducci, E. J., Martin, E. J., & Longridge, T. (1982). Visual cues in the simulation of low level flight. Proceedings of the Eighth Psychology in the Department of Defense Symposium, 32-26.

- V Visual cues used by pilots to maintain altitude in low level flight simulation were examined. In particular, terrain texture in the form of black vs. white topped inverted cones, the presence or absence of vertical development, and the effects of rate of motion on terrain features were investigated using pilots who varied in flying experience. Less experienced pilots demonstrated increases in their mean altitude and RMS deviation with an increase in airspeed or with an increase in airspeed combined with a lack of vertical development in terrain features. Experienced pilots, on the other hand, only showed increases in mean altitude and RMS deviation with an increase in airspeed. No differences were found between the all black and the white topped cones.

Rinalducci, E. J., Patterson, M. J., & DeMaio, J. (1984). Static vs. dynamic presentation of visual cues in simulated low level flight. Proceedings of the Ninth Psychology in the Department of Defense Symposium, 667-671.

- V The present study examined three visual display environments (i.e., a valley floor, a valley floor with walls, and a valley floor with walls and inverted pyramid terrain features) using different display presentation modes (i.e., slides, static video, and dynamic video). Both pilot and non-pilot subjects were employed. Differences between pilot and non-pilot subjects were obtained for the accuracy of altitude estimation with the former being more accurate. Although the results were complex, both pilots and non-pilots showed in general an improvement in altitude estimation with the dynamic vs. the static mode of presentation and with increasing complexity of the visual scene. Resolution of the display image was also shown to be an important factor. The results of this study have relevance to the development of CIG and the evaluation of the simulator visual environment.

Rinalducci, E. J., Patterson, M. J., Forren, M., & Andes, R. Jr. (1985). Altitude estimation of pilot and non-pilot observers using real-world scenes. Proceedings of the Third Symposium on Aviation Psychology, 491-498.

- P,V The present investigation was primarily concerned with the perceptual factors associated with low altitude flight, and was directed towards the assessment of the ability of pilots to accurately estimate altitude using a psychophysical technique. Pilot and non-pilot observers in the study were required to estimate altitude from photographs taken at different altitudes over six terrain areas in the Southwestern United States. These terrain areas differed in various cue factors such as object density, objects of known size, vertical development, and shading. In general, the results indicated that pilots were more accurate in their estimates than non-pilots, but both groups showed a similar pattern of responding to the different terrains. The ability of pilots and non-pilots to

estimate altitude appeared to depend upon the presence of certain cue factors. Recommendations are made relative to the assessment of pilot's ability to estimate altitude before and after low altitude flight training.

Additional comments from article: The cues used [by the subjects] to estimate altitude ...include 1) the size of foliage, trees, etc., 2) the size of objects of known size, 3) the distance to the horizon, 4) the angle to the ground, 5) a change in the position of a specific object (i.e., a reference point), and 6) a "feeling" of altitude.

Robertson, A. R. (1977). The CIE 1976 color-difference formulae. Color Research and Applications, 2, 7-11.

V This paper discusses the use of two approximately uniform color spaces (CIE 1976 $L^*a^*b^*$ and CIE 1976 $L^*u^*v^*$) and associated color-difference formulae. The CIELUV formula has, unlike the CIELAB formula, a diagram associated with it. The CIELUV formula is particular importance in color mixture and differences in color television. Choice of which formula to use (i.e., CIELAB or CIELUV) depends upon whether additive color mixture is to be represented by straight lines (CIELUV) or if the data is to be compared with data from users of the Adams-Nickerson type formulae (CIELAB).

Rogers, B. K., Stephens, C. W., & Oatman, A. B. (1991). 12th I/ITSC-1990: SIMNET fighter aircraft application. Proceedings of the Thirteenth Annual Interservice/Industry Training Systems Conference (pp. 347-355).

V This paper describes the preliminary investigation defining problems of expanding realtime simulation of fighter aircraft to a distributed simulation network. The 12th Interservice/Industry Training Systems Conference was selected as the test site to prove the concept. I/ITSC provided an arena for linking simulators from several manufacturers and laboratories. Six fighter aircraft simulators participated in the network along with a simulated ground control intercept (GCI) station and semi-automated forces providing threat aircraft.

Additional comments from article: Prior to this application of the SIMNET protocol, numerous concerns regarding the ability to network fighter aircraft using distributed simulation had surfaced. Some believed the dead reckoning of models and the large changes in position associated with fighter aircraft would cause several undesirable side effects which would render SIMNET useless in the high 'G,' rapidly changing A-A environment. Some of those concerns include: different CPU speeds (simulator, visual, NIU), weapon

effects and fly-outs, and the ability to integrate an NIU to the simulation host...Conclusion: SIMNET works for fighter aircraft simulators and will be implemented in the MULTIRAD program at AL/HRA to network 2 F-15 MASS, 2 CETs, several AITs, and a common threat simulation system. The MULTIRAD program will continue researching team training concepts and extend the capabilities of networked simulation. The first applications will be to provide a research testbed for beyond visual range (BVR), A-A engagements. As less costly and more capable visual systems become available, application to A-G missions for networked simulators will be made. SIMNET offers an immediately available method of linking ground and aircraft simulators for large force-on-force simulations. By maintaining the basics of the SIMNET protocol the capability of connecting into the Army's existing network exists for truly integrated joint training exercises. Incorporating full-up weapon systems trainers, within a TEMPEST area, into a realtime network allows practice with all aircraft avionics and employment of actual tactics along with all team members. These type exercises are not available now, short of actual combat. Team training will be the largest benefit of realtime, networked simulation.

Scott, T. D., & Sternberg, J. J. (1976). Photometric measurement of target-background contrast. (Technical Report No. ARI-RM-76 17). Alexandria, VA: Army Research Institute for the Behavioral and Social Sciences. (NTIS No. AD-A076 819/2) (Abstract Only)

V The Army has long been aware of the critical importance of surveillance activity in maximizing battlefield effectiveness. As a consequence, considerable effort has been directed toward developing a wide variety of surveillance systems. Surveillance system effectiveness is not simply a function of hardware component characteristics, but rather depends heavily on the performance of the human component. Thus, determination of human performance characteristics is necessary to adequately evaluate overall systems performance levels as well as to identify causal factors which contribute to suboptimal performance. The Army Research Institute for the Behavioral and Social Sciences (ARI) has traditionally had a considerable interest in the evaluation of surveillance systems performance and has been particularly concerned with the performance of the human component under realistic operational conditions. In all surveillance systems the human component receives information about the tactical environment in either visual or auditory form, and most systems rely heavily on the observer's visual processes. For this reason the Army has recently been concerned with identifying and quantifying major variables affecting visual target detection performance of observers directly viewing a tactical scene (or remotely viewing a scene via a display).

Shneiderman, B. (1987). Designing the User Interface: Strategies for Effective Human-Computer Interaction. Reading, MA: Addison-Wesley Publishing Company, Inc.

V This text describes issues regarding human-computer interface. It offers guidelines for data display, data entry, dialogue design, command language, error messages, and user manuals. It discusses such issues as accommodating human diversity, differentiating between expert, intermittent user, and novice needs, also menu selection systems, keyboard design, pointing devices, speech recognition and generation systems, displays, printers, system messages, screen design, color, windows, and also design, testing, and evaluation. It illustrates methods of getting the user's attention, including intensity, marking, size, choice of fonts, inverse video, blinking, color, and audio. The text brings up the problem of too slow / too fast interaction (factors affecting display rate and response time), indicating that the majority of people prefer more rapid interactions (less than one second) and that lengthy response times (longer than 15 seconds) are generally detrimental to productivity, increasing error rates and decreasing satisfaction. The theoretical foundations for response times and display rates are discussed, including principles of closure, short-term memory limitations, chunking, information-processing capabilities, and problem-solving abilities. The text concludes that if cost is not excessive, the frequently mentioned two-second limit for response time seems appropriate for many tasks (simple commands). Additional issues on which this text focuses are effective screen design, including density, grouping, layout complexity, and window design. Finally, the author offers some guidelines on the use of color.

Smith, W. (1988). Standardizing colors for computer screens. Proceedings of the Human Factors Society-32nd Annual Meeting, 1381-1385.

V This paper provides a description of the color standard draft proposal developed for ISO (International Organization for Standardization). Included in the paper are specifications for color values to ensure color perception and interpretation, and an Annex of non-normative guidelines.

Sticha, P. J., Singer, M. J., Blacksten, H. R., Morrison, J. E., Cross, K. D. (1990). Research and methods for simulation design: State of the art. (ARI Technical Report No. 914). Alexandria, VA: U. S. Army Research Institute for the Behavioral and Social Sciences. (NTIS No. AD-A230 076)

F,P This report reviews the empirical results and analytical methods available to the training-device designer for tradeoff analyses necessary to produce

cost-efficient training-device designs. It addresses the problem of training system optimization in three ways. First, it describes existing methods that can aid training-device design functions. The function and operations of methods are compared to the model for the optimization of simulation-based training systems (OSBATS) developed for this project. Second, it reviews the research on several issues related to training-device optimization. The issues covered in the review include training-device fidelity, instructional features, skill acquisition, skill retention, transfer of training, and cost estimation. Third, the review organizes the requirements for future research on these topics and sets priorities for research topics based on their cost and the benefit they could offer to the training-device designer. The review focused on quantitative models that can be used to estimate training cost and effectiveness and to determine optimal levels of training-device design variables. The research plan identifies the topics that reduce critical gaps in our knowledge at a reasonable cost. Research addressing a) relative impact of fidelity features and instructional features on training effectiveness, b) effects of student aptitudes on training-device design, and c) organization of nonmonetary reasons for simulation-based training can produce a moderate benefit at a relatively low cost. The most critical research issues involve the impacts of training-device fidelity and instructional features on training effectiveness. This review provides information that may be used by researchers who wish to develop or improve methods to aid the training-device designers. Designers may use this review to identify methods to aid the training-device design process and individuals who manage research programs may use this information to set priorities for future research efforts.

Stokes, A., Wickens, C., & Kite, K. (1990). Display technology: Human factors concepts. Warrendale: SAE.

- V This book has a chapter on "Color and Pictorial Displays" which discusses the advantages and limitations of the use of color in various displays (e.g., aircraft, automobile, etc.). It is suggested that color use can be both quantitative and qualitative in function and that color-coding can involve a single-purpose code, environmental color, and a dual-purpose code. The authors also point out that the preferences for certain colors does not necessarily mean a difference in performance with various colors. Any use of color must take into account not only hue, but also saturation and luminance. It is also noted that color specification systems such as those proposed by the CIE still possess certain limitations. In addition, temporal and spatial variables can affect color coding, as well as individual differences. The authors note that universal standards for color selection in aviation have yet to be determined, and this is probably due to the fact that a generally applicable metric of color contrast has yet to be developed. Basic

discriminable colors include blue, red, yellow, green, orange, purple, black, white, and brown. Population stereotypes for color also need to be taken into account. It has been reported that full-color displays are preferred by pilots (especially for head down displays), and that performance is superior when using the full-color pictorial displays.

Stonge, J. R. (1988). The role of psychological fidelity in training systems acquisition. Proceedings of the Tenth Annual Interservice/Industry Training Systems Conference (pp. 356-361).

F In training system design and acquisition, some aspect of the procurement addresses the fidelity of the training system. Normally, physical fidelity is the sole concern, although some of the more sophisticated designs and acquisitions have also looked at the concept of functional fidelity as being equal to or greater than that of physical fidelity. This emphasis on functional fidelity applies to two-dimensional simulation of the three-dimensional systems. Experience has demonstrated, however, that regardless of the quality of both physical and functional fidelities, a substantial number of training systems are unused, unappreciated, and unsuccessful for their planned training mission. This paper identifies a missing ingredient in the study of training system fidelity, that of psychological fidelity. Whereas physical fidelity has to do with how closely something looks like the real thing, and functional has to do with how well it acts like the real thing, psychological has to do with how well it is perceived to train like the real thing. While related to user acceptance, psychological fidelity is the environmental perception of the learner, not the instructor. Users forget that they are in training, and learn as if working with actual equipment. The elements associated with psychological fidelity are identified. Relationships between psychological fidelity and both physical and functional fidelity are specified. Directions for including psychological fidelity elements during the fidelity analysis process are provided. Finally, recommendations are given for a methodology for incorporating psychological fidelity in training system acquisition in the next decade.

Taylor, J. M., Murch, G. M., & McManus, P. A. (1989). TekHVCTM: A uniform perceptual color system for display users. Proceedings of the SID, 30, 15-21.

V The authors describe the development and implementation of a new display-based color system. The HLS color system was developed by Tektronix in 1978. The overall goal was to create a system which was more visually uniform, more intuitive and therefore user-oriented. The three-dimensional color-space involves hue, lightness, and saturation in a color

solid represented by a double-ended cone. The new color system developed by Tektronix Laboratories is known as TekHVCTM uses the three independent color parameters of hue, value, and as. The HVC system was derived from the 1976 CIE Uniform Chromaticity Scale u', v' diagram and the related CIE L^*, u^*, v^* (CIELUV) color metrics. An accurate description of the HVC color solid and the underlying model requires a series of algorithms which access device colorimetry and calibration data.

Thorell, L. G., & Smith, W. (1990). Using computer color effectively. New York: Prentice-Hall.

V This is a well-illustrated book specifically on the use of color in video displays. Chapters on the specification of color with a description of the different color spaces, the manipulation of color on displays, and guidelines for the use of color in computing are included. Extensions the CIE space include the 1976 UCS (uniform color space), CIELUV and CIELAB. The UCS improves the CIE description of color appearance, the CIELUV is the primary color space recommended by the CIE and is a metric for expressing color differences which includes the lightness response of the eye, the CIELAB is the second uniform color space recommended by the CIE and is often used to capture the color appearance of subtractive color mixtures. The advantages of CIELUV, which is for additive color mixtures and is probably most related to video displays, are presented along with the limitations of this color space.

Uliano, K. C. (1991). Aviation trainer technology test plan. (Contract No. N61339-89-0045). Orlando, FL: Institute for Simulation and Training, University of Central Florida.

D Until recently, flight simulators have been used for training one cockpit crew at a time. New technological advancements in the areas of computer science, simulation engineering, and data communication techniques are paving the road toward advancing networked simulation systems across geographical locations. Through realistic networking capabilities, low cost trainers now can be networked to provide for more realistic training scenarios, as aircraft normally are flown in groups of two or more in training, as well as on actual missions. With increased use of networking in large scale training exercises, the problem of longer data transmission delays between the simulators is inevitable. Many studies have been conducted to determine the training outcome of intrasimulator time delays; however research in the new area of intersimulator time delays is scant. The question that arises is how much lag time between simulators will be acceptable to the trainees, and how much lag time will be acceptable for an effective transfer to the actual aircraft. Standards and

training criteria have evolved from completed intrasimulator delay research, including the military specification, MIL-F-8785C, which allows for an overall maximum time delay, for Level 1 aircraft simulation, of only 100 msec between cockpit control input and aircraft response. A Level 1 rating for a simulator equates with a "satisfactory" rating, a Level 2 rating is "acceptable", but "unsatisfactory", while a Level 3 rating is "unacceptable". Levels 2 & 3 have established upper limits at 200 and 250 msec, respectively. A recent draft standard for distributed interactive simulation which will be processed through the IEEE (Institute for Simulation and Training, 1991), has arbitrarily set the maximum intersimulator transmission delay at 500 msec. Even though there are limits set by the military for lag time within a Level 1 simulator, no such limits have been formally set for allowable time lags between simulators. This study provides initial data and insights into the intersimulator transmission delay problem, and measures differences in pilot performances as a function of time delays inserted into the simulation. Eight pilots were exposed to four delay conditions: 0 msec, 250 msec, 500 msec, and 750 msec. In the testing phase of the study, each pilot flew 20 air-to-air engagements against his adversary. For each intercept, the pilot flew a delay condition randomly assigned beforehand. Pilots were also randomly assigned to either an advantageous or disadvantageous starting position. After each trial, the subjects rated the simulation in terms of how it may have affected their ability to perform certain tasks. Objective measures included number of missiles fired, hit/miss ratio, and number of gun and missile kills. There was no significant trial (time) effect, no significant effect of delay in subjective pilot ratings across delay conditions, no significant differences for percentage of kills by type (i.e. either missile or gun) across each delay condition, and no significant differences in the hit/miss ratio as a function of delay condition. However, several noticeable trends became apparent. Namely, pilots had the most difficulty with predicting the effectiveness of their own countermeasures (i.e. flares). Analysis of the subjective ratings across delay conditions showed a general increase in each task component rated as delay time was increased from 500 to 750 msec. There was a trend in the kill-type percentage. In the 0 msec delay condition, missile kills accounted for slightly over 60% of the kills. That decreased to 47% in the 250 msec condition, and then to 27% in the 500 msec condition. There was an increase, however, in the 750 msec condition to 42% of the kills being missile kills. Also, for those pilots who began the trial in the advantageous starting position, their hit/miss ratio decreased as a function of delay. Those pilots starting in the disadvantageous position saw an increase in their hit/miss ratio. The latter is due to the fact that pilots in the disadvantageous position survived longer because of the transmission delay on the missile flyout algorithms. There are some far reaching implications of these findings. For the most part, pilots do not perceive that delays up to 750 msec are affecting their task performance. However, some important observations can be made when the objective data is analyzed. First, as delay

increases up to 500 msec, pilots rely less on their missiles and more on their guns. This is no doubt due to the effect delay has on probabilistic missile models. Pilots note that their missiles are, as one pilot states, "...going stupid." They therefore mentally note that their missiles are not as effective, and subsequently maneuver in for a gun kill which is affected little, if any, by delay. Again, this trend is noted up to 500 msec, but the trend does not continue to the 750 msec condition and no viable explanation can be offered. The data on the hit/miss ratio as a function of delay also supports this contention. Pilots in an advantageous position are less successful with each missile fired as the delay is increased. To compensate, they fire more missiles in hopes one will hit since in the ASAT model one missile hit is scored as a kill. This could potentially have serious training implications. For those in the disadvantageous position, their hit/miss ratio is increasing simply because they remain alive longer and have more of a fighting chance as delay increases.

Uliano, K. C., Lambert, E. Y., Kennedy, R. S., & Sheppard, D. J. (1986). The effects of asynchronous visual delays on simulator flight performance and the development of simulator sickness symptomatology. (Contract No. N61339-85-D-0026). Orlando, FL: Naval Training Systems Center.

D,P This research effort involved an experiment investigating the effect of asynchronous visual delays on simulator flight performance and the development of simulator sickness symptomatology. The SH-60B Vertical Takeoff and Land (VTOL) Simulator, part of the Navy's Visual Technology Research Simulator (VTRS) program was used to investigate this issue. Three operational visual throughput delays with varying amounts of asynchrony were tested: 215 ± 70 msec, 177 ± 23 msec, and 126 ± 17 msec. Twenty-five experienced pilots flew three 40- or 60- minute sessions with two simulator tasks (air taxi and slalom) under each of the lag conditions. Pilots flew one session per day for three days with the lag condition changing each day. Objective and self-report indices were collected and, while results showed no difference between lag conditions, paper-and-pencil illness ratings reflected a high initial incidence of illness (46% on Day 1) followed by rapid adaptation upon subsequent exposure. Simulator performance, however, was differentially affected by lag with the longest lag producing the worst performance. Finally, relationships between sickness indices, flight performance data, and other variables are presented and discussed along with observations, recommendations, and areas for future research.

Ward, F. E., Greene, F., & Martin, W. (1983). Color matches and discrimination functions for selected hues. Proceedings of the Human Factors Society-27th Annual Meeting, 249-253.

V The purpose of this study was to measure color matching and discrimination in the hue, size, luminance, and adaptation ranges that have relevance for cockpit CRT display viewing applications. These data were then compared to current literature on color discrimination to determine their suitability for CRT design applications. The stimuli were presented in a Maxwellian-view optical system. Six subjects participated in the study on color matching. The subject was required to match the standard and the average match value was then displayed. The subjects were then required to offset the match until a color difference was just perceptible. A field-size effect was obtained (0.5 and 2 degrees), with the smaller field requiring larger offsets for discrimination of a color difference. When subjects were required to produce a discriminable color difference, these were nearly always larger than three standard deviations. The authors suggested that hues should be at least 0.032 UCS units apart, and developed an empirical model to describe the color separation in 1960 UCS space, necessary for adequate discrimination.

Weitz, J., & Adler, S. (1973). The optimal use of simulation. Journal of Applied Psychology, 58, 219-224.

F,P The problem of when to stop training on a simulator and the advantages and disadvantages of simulator fidelity are discussed. A study illustrating the paradigm that might be used to investigate these variables is described. Some suggestions are made for the use of simulation training.

Additional comments from article: Overtraining on a simulator beyond the level at which task context or strategy has been mastered leads to a decrement in positive transfer to the operational situation....Since it appears that, in at least some situations, a simple simulator of a relatively complex task will produce as much positive transfer to the real task as will a more elaborate simulator with greater fidelity, one might further expect an interaction effect between overtraining and simulator fidelity. This interaction would be apparent if overtraining on a more complex simulator resulted in the dominance of simulator content-specific habits that would subsequently interfere with posttransfer performance. The hypothesis here is that overtraining on a simulator of greater fidelity will lead to the greater transfer decrement....In general, it would seem that training should stop soon after the operation of the mechanism is learned and before habits specific to the performance on the simulator are developed....It would also seem that a training device may require less fidelity and briefer training periods than one might at first imagine.

Westra, D. P., Lintern, G., Sheppard, D. J., Thomley, K. E., Mauk, R., Wightman, D. C., & Chambers, W. S. (1986). Simulator design and instructional features for carrier landing: A field transfer study. (Contract No. N61339-85-C-0044). Orlando, FL: Naval Training Systems Center.

P,V A transfer-of-training experiment was conducted as the culmination of the carrier landing behavioral research program at the Visual Technology Research Simulator (VTRS) at the Naval Training Systems Center (NAVTRASYSCEN) in Orlando, Florida. The results of this experiment provide information on the design and use of simulators for training the aircraft carrier landing task. The results also provide input on design issues for the Navy's new T-45 training system (T-45TS). Two visual display variables and two simulator training variables were selected for inclusion in this experiment: scene detail (day contrasted with night); field of view (wide versus narrow); approach type (circling, modified straight-in or segmented); and number of simulator trials (20, 40, or 60). A total of 72 student pilots were trained on the VTRS prior to going through the Field Carrier Landing Practice (FCLP) phase of their pilot training program. The performance of these students at FCLP was contrasted with that of a group of 54 students who did not receive simulator training. Results show that students trained in the simulator performed better at FCLP than students in the control group. 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 also 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. The pilots who trained with a segmented approach schedule did as well or better on transfer to FCLP than those training with the modified straight-in approach schedule or all circling approaches. The segmented approach schedule is recommended as it involves the least time in the simulator.

Westra, D. P., Sheppard D. J., Jones, S. A., & Hettinger, L. J. (1987). Simulator design features for helicopter shipboard landings: II. Performance experiments. (Technical Report No. 87-041). Orlando, FL: Naval Training Systems Center.

D,F,P,V The Vertical Takeoff and Landing Simulator (VTOL) at the Naval Training Systems Center's (NTSC) Visual Technology Research Simulator (VTRS) was used to evaluate the effects of five simulator design features on performance for helicopter shipboard landings. The research was designed to evaluate the effect of current design features of the SH-60B Operational Flight Trainer (OFT), and other design features for training helicopter shipboard landings. The design features

investigated were: 1) scene detail (SH-60B OFT scene versus an upgraded scene), 2) field of view (wide versus a smaller SH-60B OFT field of view), 3) dynamic seat cueing (on versus off), 4) dynamic inflow (standard aero model available in existing trainers versus an updated aero model), and 5) visual transport delay (117 msec versus 183 msec). Twelve SH-60B helicopter pilots performed an approach, hover, and landing task on a representation of an FFG-7 frigate, and a precision hover (over the deck of the frigate) and landing task. The two tasks were performed separately and constituted two independent experiments. Two environmental factors were included. Calm and moderate seastate conditions were used to manipulate task difficulty during the approach, hover, and landing task, and vertical wind gusts were included as a standard feature in the precision hover task. Pilots were separated into low and high experience levels, defined in terms of their shipboard landing experience. Results indicated large effects due to field of view and smaller effects due to scene detail, dynamic inflow, and visual delay. All of these results favored the higher fidelity conditions. Dynamic seat cueing did not appear to offer any meaningful positive benefit for performance. Based on these results, recommendations were made for simulator design and for the next phase of helicopter shipboard landing research at VTRS. The next phase of research will involve an in-simulator experiment which is now under development. The research reported here concludes the first phase of research involving performance experiments at VTRS.

Whiteside, T.C.D. (1983). Simulators and realism. Quarterly Journal of Experimental Psychology, 35(A), 3-15.

F,P The objectives of simulation are discussed on the basis of training in procedures or neuromuscular skills, and in relation to the amount of realism required. Motion sickness arising from inadequate coordination of visual and motion cues, is considered in relation to fixed and moving base simulators. In the perception of distance and size, the role of ocular convergence is discussed and an experimental approach suggested. The mentally stressful effects of increased responsibility, as robots enable the operator to extend his output, are discussed in relation to its covert symptomatology and to advanced flight concepts.

Wilson, D. L., & Crawford, R. (1989). Color contrast requirements for legibility of color symbology displayed against color backgrounds. Proceedings of the Human Factors Society-33rd Annual Meeting, 1372-1377.

V The authors employed a Signal Detection paradigm in a symbol recognition task in order to determine how far apart, in CIE/UCS color space, symbol and background chromaticities need to be in order for observers to reliably recognize the symbol. A d' of 3.0 which is near perfect performance is related to symbol/background chromaticity differences of 0.06 units in the 1976 UCS color space. The authors indicate that application of this research is relevant to problems in color coded symbology on complex moving maps and situational awareness displays.

Witmer, B. G., & Knerr, B. W. (1991). Guidelines for embedded training decisions. Proceedings of the Thirteenth Annual Interservice/Industry Training Systems Conference (pp.62-70).

P,V While Army policy requires training developers to consider embedded training (ET) first and foremost among training options, effective implementation of this policy has been hampered by the lack of specific procedures for determining what to embed early in prime system development. This paper describes specific procedures that assist a user in making those early ET decisions. Although task information has traditionally been the primary criterion used in selecting media for training, it is thought to be less important in deciding when to use ET than are the following factors: policy; system availability for training; the technical feasibility of ET implementation; the effects of ET on system reliability, availability, and maintainability; the impact of ET on system manpower and personnel requirements; the need for training-specific interface hardware; safety; and cost-effectiveness. These factors are incorporated in three sets of flowcharts, designed to be used in different stages of the acquisition process.

Wyzecki, G., & Stiles, W. S. (1982). Color science. New York: Wiley, 2nd ed.

V This work provides an excellent general reference covering a variety areas of color science, either directly (e.g., color differences, color specification, etc.), or indirectly (e.g., dark and light adaptation, etc.).

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