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Scene-linked Symbology to Improve Situation Awareness

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1. SUMMARY

This paper reviews recent research conducted in the Flight Management and Human Factors Division of NASA Ames Research Center on superimposed symbology (as found on HUDs and HMDs). We first identify various performance problems which suggest that superimposed symbology impairs pilots' ability to maintain simultaneous awareness of instrument information and information in the forward visual scene. Results of experiments supporting an attentional account of the impairment are reported. A design solution involving the concept of "scene-linked" symbology is developed, and experiments testing the design solution are reported. An application of the scene-linking concept, in the form of a candidate HUD to support ground taxi operations for civil transport, is described.

2. INTRODUCTION

2.1. Information acquisition and situation awareness

Piloting an aircraft is a demanding activity, in part because pilots have to be aware of many different forms of information. Most of this information is extracted from two distinct sources: the instrument panel, or "near domain", and the forward visual scene, or "far domain". In a standard flight deck, the instrument panel is located underneath the windshield, making it physically impossible to see both domains simultaneously. As a result, pilots must adopt a sequential acquisition scanning strategy whereby information is sampled from one domain and then the other. This strategy requires time consuming actions, such as eye and head movements, and reaccommodation of the eyes. These actions continually interrupt the process of information acquisition. Furthermore, as long as the pilot is looking at one domain, a sudden event (or sudden state change) in the other domain goes undetected.

For various reasons, then, the physical separation between near and far domains has a negative effect on situation awareness. At first glance, the problem would seem to be solved by Head-Up Displays (HUDs) and Helmet-Mounted Displays (HMDs), which superimpose graphic depictions of instrument symbology directly over the far domain. By bringing near and far domains into the same forward field of view, superimposed symbology devices make it physically possible to process near and far domains in parallel (Ref 1, 2). Intuitively, then, it would seem that these devices would enhance a pilot's situation awareness, relative to the traditional configuration.

2.2. Performance problems

Over the years, however, researchers have identified a number of performance problems with superimposed symbology. These problems suggest that, far from facilitating joint awareness of near and far domains, superimposed symbology actually reduces the level of joint awareness. For example, Fischer, Haines, & Price (Ref 3) found that pilots flying simulated approaches using a HUD sometimes failed to notice runway incursions. No such failures were observed among pilots flying with conventional head-down instrumentation. Weintraub, Haines, & Randle (Ref 4) found similar results using static displays. Fischer et al. confounded location of the instrumentation (superimposed versus head down) with type of instrumentation; the HUD included contact analog symbology, whereas the head-down instrumentation did not. It is not clear, then, whether the failure to notice incursions was due to the change in the location of the symbology or to the change in the symbology itself. Wickens & Long (Ref 5) recently addressed this problem by presenting the identical symbol set either head-down or head-up. Following breakout, pilots flying instrument approaches took, on average, 2.5 seconds longer to respond to an unexpected runway incursion when the symbology was head-up compared to head-down.

A second performance problem has emerged from level flight simulation tasks at NASA-Ames. Brickner (Ref 6) had subjects fly a simulated helicopter through a slalom course demarcated by virtual pylons. Subject pilots were instructed to fly around the pylons while maintaining an altitude of 100 feet. In one condition, altitude information was available only from naturally occurring environmental cues in the graphic simulation of the far domain (e.g., pylon size). In another

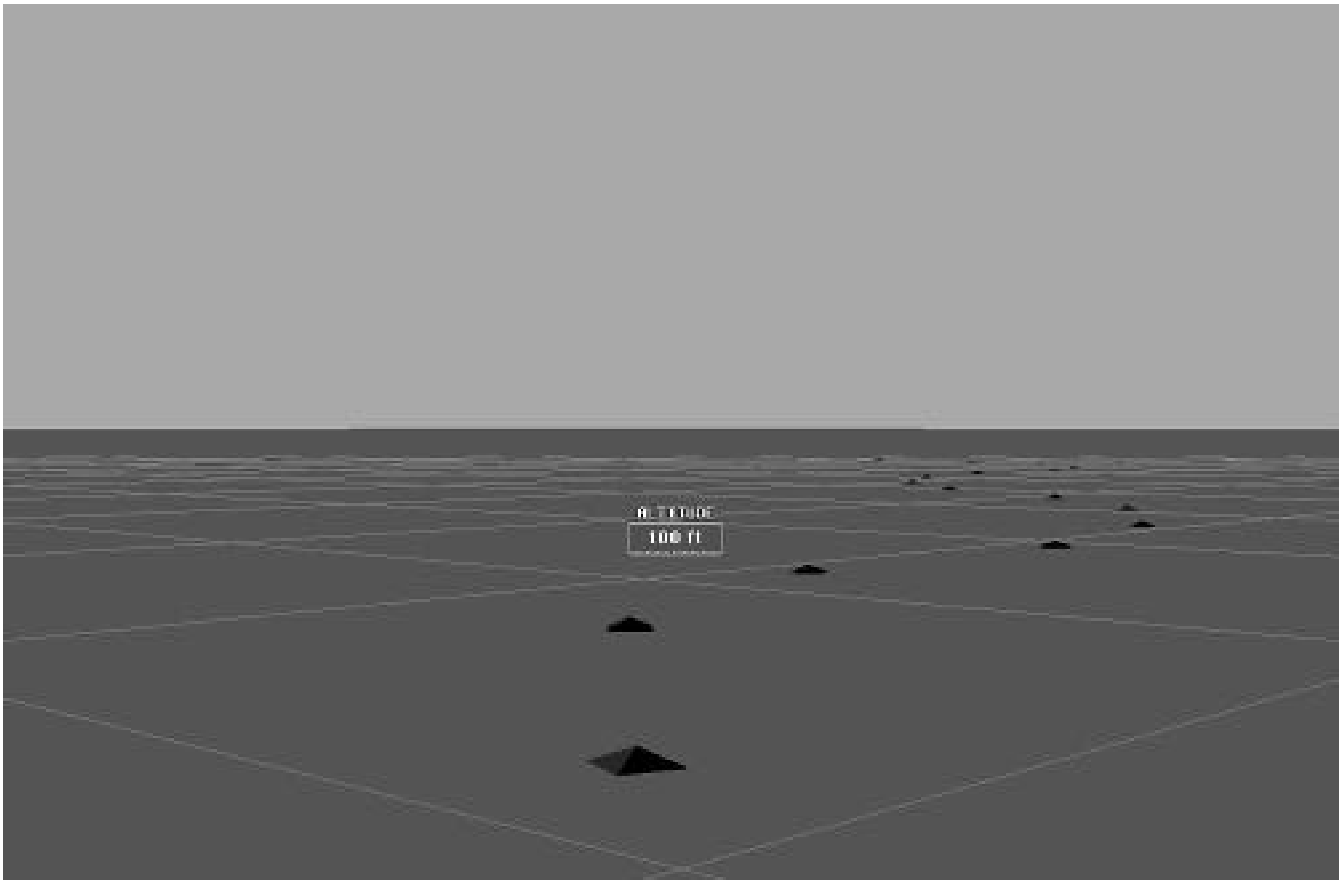

Figure 1. Part-task simulation environment showing ground track to be followed (pyramids) and digital superimposed symbology (currently showing 100 ft). (After Foyle et al., Ref 7).

condition, these natural cues were supplemented by a superimposed digital readout of current altitude (for brevity, we refer to the digital symbol as a "HUD"). Not surprisingly, the presence of the digital HUD improved altitude maintenance performance compared to the no-HUD condition. However, this performance benefit was obtained at the cost of an increase in the number of collisions with the pylons. Thus, superimposing digital symbology on the forward visual scene yielded a performance tradeoff: the symbology supported more accurate altitude maintenance, at the cost of less accurate path maintenance.

Foyle, McCann, Sanford, & Schwirzke (Ref 7) found a similar tradeoff using a slightly different flight task and a different performance measure. Subjects flew a curving path defined by small pyramids on the ground, while maintaining an altitude of 100 feet (see Figure 1). Random buffeting was introduced in both the vertical and horizontal dimensions throughout each 2-minute flight; the dependent measures were flight path error (measured by root mean square deviations from the designated path) and altitude error (measured by root mean square deviations from 100 feet). Following Brickner (Ref. 6), altitude information was available either from environmental cues in the simulated far domain, or environmental cues supplemented by a digital altitude HUD. Results were similar to Brickner's: the presence of the HUD decreased altitude maintenance error, but increased path following error. In subsequent discussion, we refer to this performance pattern as the altitude/path performance tradeoff.

2.3. Source of the performance problems

These performance problems suggest that superimposed symbology actually reduces a pilot's joint awareness of events in the near and far domains. Why is this the case, when common sense indicates that superimposing symbology on the far domain should have the opposite effect? One possibility, discussed by Roscoe and his colleagues (Ref 8), is that even though superimposed symbology is collimated to appear at visual infinity, there are still a variety of perceptual cues to remind the pilot that the symbology is much closer than the far domain (for example, scratches or dirt on the combiner glass of a HUD). Therefore, when processing superimposed symbology the eye accommodates inward, blurring the out-the-window scene to where concurrent processing of the symbology and the world is prevented. However, this account cannot explain the altitude/path performance tradeoffs reported by Brickner (Ref 6) and Foyle et al. (Ref 7), or the increased time to notice runway incursions reported by Wickens & Long (Ref 5). In these studies, the superimposed symbology and the out-the-window scene were part of the same synthetic graphical display; thus, both the superimposed symbology and the far domain were at the same optical distance from the eye.

A second possibility appeals to limitations on the ability of the visual system to process superimposed symbology and the world simultaneously (Ref 9, 3, 7). This hypothesis follows naturally from "object-based" models of visual attention (Ref 10, 11). According to these models, visual processing occurs in two successive stages. In the first stage, visual elements with similar perceptual properties are grouped together to form distinct perceptual units (Ref 10, 12, 13). HUD symbology differs from the far domain on a number of salient dimensions, including color, texture, and motion (HUD symbology is either stationary or moves over a small visual area, whereas elements in the far domain are linked in a common flow field). Each of these dimensions is a powerful basis for perceptual grouping (Ref 10, 12, 13). Thus, in the first stage of processing, superimposed symbology is parsed as one perceptual group, and the far domain as another.

In the second stage, perceptual groups form the basis of attentional allocation. Importantly, limitations on visual attentional resources prevent attention from being focused on more than one perceptual group at any one time (Ref 11). Therefore, when superimposed symbology is selected for processing, it captures all available attention. Since elements in unattended groups are not processed to the point of awareness (Ref 14), attentional capture causes pilots to lose awareness of events or elements in the far domain.

Object-based models thus provide a natural account of the performance problems described earlier. The increased latency to respond to runway incursions when using HUDs (Ref 5) follows from the fact that when pilots are attending to the HUD, far domain awareness is reduced to the point where runway incursions are not noticed. The altitude/path performance tradeoffs reported by Brickner (Ref 6) and Foyle et al. (Ref 7) follow from the fact that, because attentional capture by the digital HUD reduces awareness of the far domain, departures from the flight path take longer to be noticed and corrected.

Attentional capture by superimposed symbology poses a challenge to operational efficiency and safety that grows more serious every day. This is because superimposed symbology devices are spreading rapidly beyond the military sector, where they have existed for many years. For example, one of the largest US. carriers, Southwest Airlines, is currently retrofitting its entire fleet with HUDs. HUDs are also now available to the general aviation market. In the near future, superimposed symbology devices are likely to be incorporated into a host of additional operating environments. These include automobiles, industrial assembly lines, and occupations, such as fire fighting, where people must operate in low-visibility conditions.

Here at NASA Ames, concerns about the operational implications of attentional capture have motivated two lines of research. One line has verified a key empirical prediction of the capture account, and identified the perceptual characteristic most responsible for capture. The other line has incorporated this information into candidate HUD displays, which are then tested to determine whether they alleviate the performance problems associated with capture. The rest of this article summarizes these programs.

3. TESTS OF ATTENTIONAL CAPTURE

3.1. Introduction

Consider the following situation. A pilot is viewing a visual scene consisting of a runway, just prior to touchdown, together with superimposed symbology on a HUD. The task is simply to identify two discrete objects. If superimposed symbology captures attention, processing the two objects should proceed in parallel if they are both HUD symbols. This follows from the fact that the symbols are part of the same perceptual group, and attention is distributed equally across the elements of a perceptual group (Ref 10). However, if one object is a HUD symbol and the other is a feature on the surface of the runway, processing the two objects should be serial, because attention must be switched from the HUD to the far domain before the object on the runway can reach awareness. Since switching attention takes time, the attentional capture hypothesis makes a straightforward prediction: the pilot should respond to the task more slowly when one object is a HUD symbol and the other object is an element on the runway surface, compared to when both objects are HUD symbols. We recently completed a series of laboratory experiments testing this prediction (15, 16, 17).

3.2. Experiment 1: A Test of Attentional Capture

Following Weintraub et al. (Ref 4), subjects viewed computer-generated displays consisting of a set of stationary blue symbols (collectively referred to as the HUD) superimposed on a yellow image of a runway (see Figure 2). All far domain imagery (including the runway outline, surface features on the runway, and the

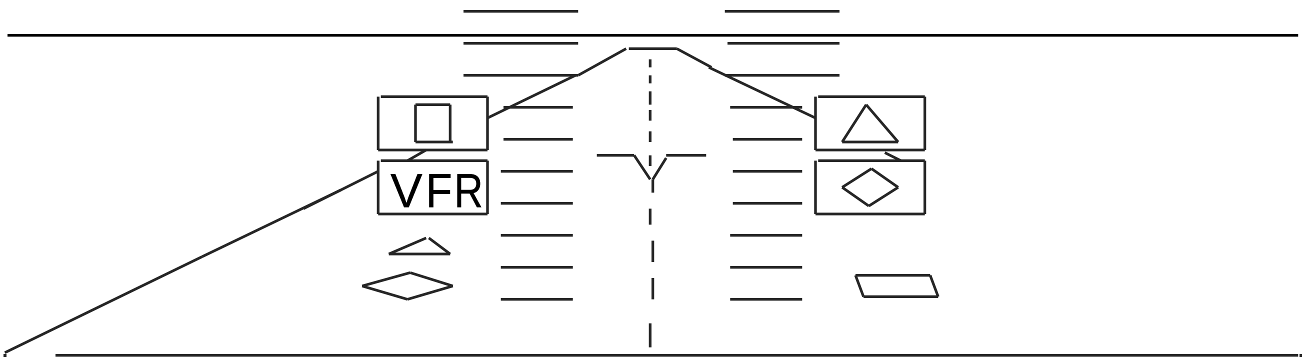

Figure 2. HUD Symbology superimposed on runway scene. Subjects' task shown was to identify VFR cue (on HUD), then visually acquire diamond (lower left on runway). (After McCann et al., Ref 15).

horizon line) was dynamic, consistent with the appearance of the far domain during final approach. The task was to first identify a three-letter cue located on the HUD. Depending on cue identity, subjects then searched either the remaining HUD symbols or the symbols on the runway surface for one of two prespecified targets - a stop sign or a diamond. If subjects saw a diamond, the runway was open, meaning the landing could continue. If subjects saw a stop sign, the runway was closed, meaning a go-around was mandated. The decision to land or go around was communicated by pressing one button if the target was a diamond, and another button if the target was a stop sign. Instructions stressed the importance of responding to the task both quickly and accurately.

Importantly, the targets and distracting symbols were the same on the HUD and on the runway; the cue signalled which domain was relevant to search, and which was not. Nevertheless, responses were approximately 100 msec faster when the relevant target was on the HUD compared to the runway surface. This result was not because the runway versions of the targets were inherently more difficult to process than the HUD versions. When the cue was altered to make it look like it, too, was on the runway surface, the response time pattern reversed: subjects were now slower when the relevant target was on the HUD than when it was on the runway. And since the displays also equated the physical distance between cue and targets between and across perceptual groups, attention switching between the HUD and the far domain provided the most straightforward account of the data. Thus, the results fully supported the hypothesis that well defined perceptual groups, such as superimposed symbology on a HUD, capture attention.

3.3. Experiment 2: What causes capture?

According to object-based models of attention, capture occurs because the visual system parses superimposed symbology as one perceptual group, and the far domain as another. In the course of developing a design solution to the problem, our first step was to identify the perceptual characteristic, or combination of characteristics, most responsible for perceptual grouping. In the first experiment, superimposed symbology was distinguished from the far domain by a number of highly salient characteristics, including differential motion, differential color, and differential viewing perspective (the HUD symbology was vertical with respect to the viewer, whereas objects in the far domain appeared as they would when viewed from above and behind). Which of these characteristics was most important in driving perceptual grouping, and hence attentional capture?

McCann et al. (Ref 16) examined the contributions of differential color and differential motion to the grouping effects in McCann et al (Ref 15). A baseline condition was provided by replicating McCann et al. (Ref 15), where the HUD symbology was distinguished from the far domain by differential motion, color, and viewing perspective. The remaining conditions were created by jointly manipulating whether the HUD and the world were shown in the same or different colors, and whether the point of regard with respect to the runway was dynamic, consistent with final approach, or "frozen" at about 5 seconds prior to touchdown. Since the HUD and the elements of the far domain were both stationary in this condition, there were no differential motion cues to support grouping.

The logic of these manipulations can be illustrated with reference to the color factor. If perceptual grouping is driven by color differences between the HUD and the far domain, then parsing the HUD and the far domain as separate perceptual groups should not occur when the HUD symbology and the far domain are drawn in the same color. In the absence of separate grouping, there should be no attentional capture. Processing should be the same regardless of whether the cue and target are both superimposed symbols, or the cue is part of the HUD and the target on the runway. Empirically, response times should be the same across the two

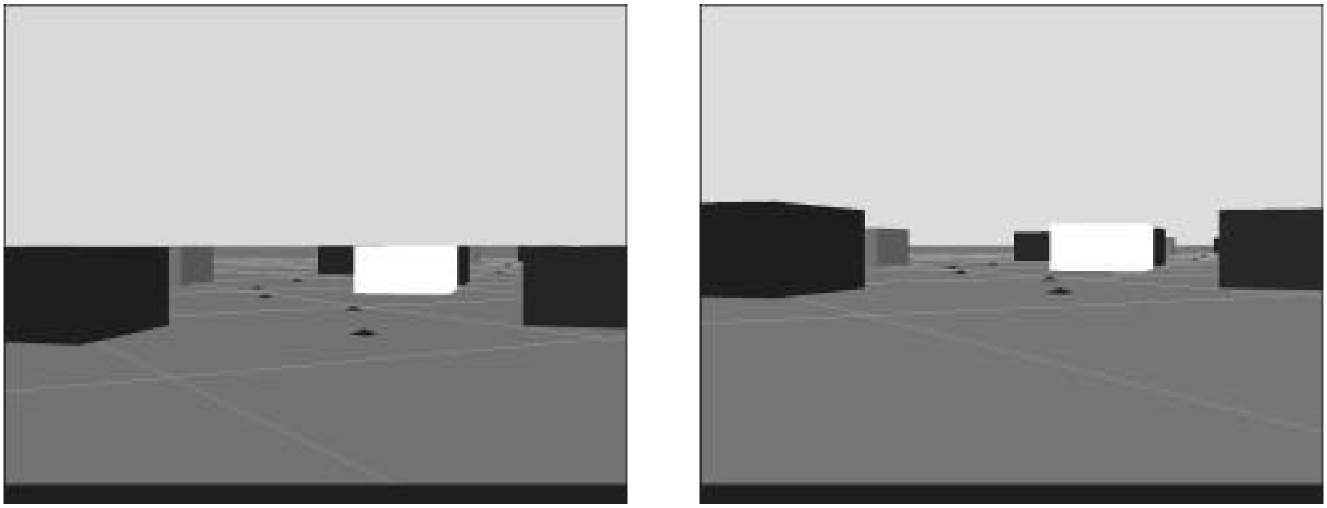

Figure 3. Flight simulation environment with virtual buildings showing current altitude at 100 feet (top panel), and below 100 ft (bottom).

conditions. Alternatively, if color is not a factor in the grouping process, the HUD should continue to be parsed as a perceptual group, distinct from the far domain. Response times should continue to be slower when the target is on the runway surface compared to the HUD. In general, our interest is in comparing the difference in response times across the two critical conditions (cue and target on the HUD versus cue on the HUD and target on the runway) to the difference obtained in the baseline condition. We can then determine whether attentional capture is driven primarily by differences between superimposed symbology and the far domain in color, in motion characteristics, or another characteristic entirely (such as viewing perspective).

The results of the baseline condition replicated the earlier finding (Ref 15) that responses were slower when the cue was on the HUD and the target was on the runway surface, compared to when cue and target were both on the HUD. This difference was virtually unchanged when the superimposed symbology and the far domain were presented in the same color. In sharp contrast, when differential motion cues were removed from the display, the difference in response time between the two critical conditions was reduced by 50 percent, a highly significant effect.

3.3.1. *Implications*

The purpose of this experiment was to identify which of the perceptual characteristics distinguishing superimposed symbology from the far domain was most responsible for perceptual grouping (and hence, attentional capture). Although differential color was an obvious candidate, the experiment suggests that differential motion, not color, plays an important role. These results have direct implications for display design. If color had been found to cause attentional capture, capture could have been reduced by simply drawing HUD symbology in colors that match the far domain. Clearly a more complex design solution is required. One possibility is considered in the next section.

4. A CANDIDATE DESIGN SOLUTION

If the primary driver behind attentional capture is differential motion between superimposed symbology and the far domain, then capture should be prevented if differential motion between the HUD symbology and the elements of the far domain is removed. A design option that achieves this goal involves replacing conventional HUD symbols with virtual symbols that appear to be physically part of the world (Foyle, Ahumada, Larimer, & Sweet, Ref 18). As the aircraft moves through the world, these "scene-linked" symbols undergo the same visual transformations as real objects. There are no differential motion cues to cause the visual system to interpret the virtual symbols as part of a perceptual group distinct from the world. In the absence of such parsing, attentional capture should be prevented, enabling pilots to process scene-linked HUD symbology in parallel with information in the far domain.

5. EXPERIMENTAL TESTS

5.1. Experiment 1: Virtual Buildings

If this analysis is correct, scene-linked symbology should alleviate performance problems found with conventional forms of superimposed symbology. A

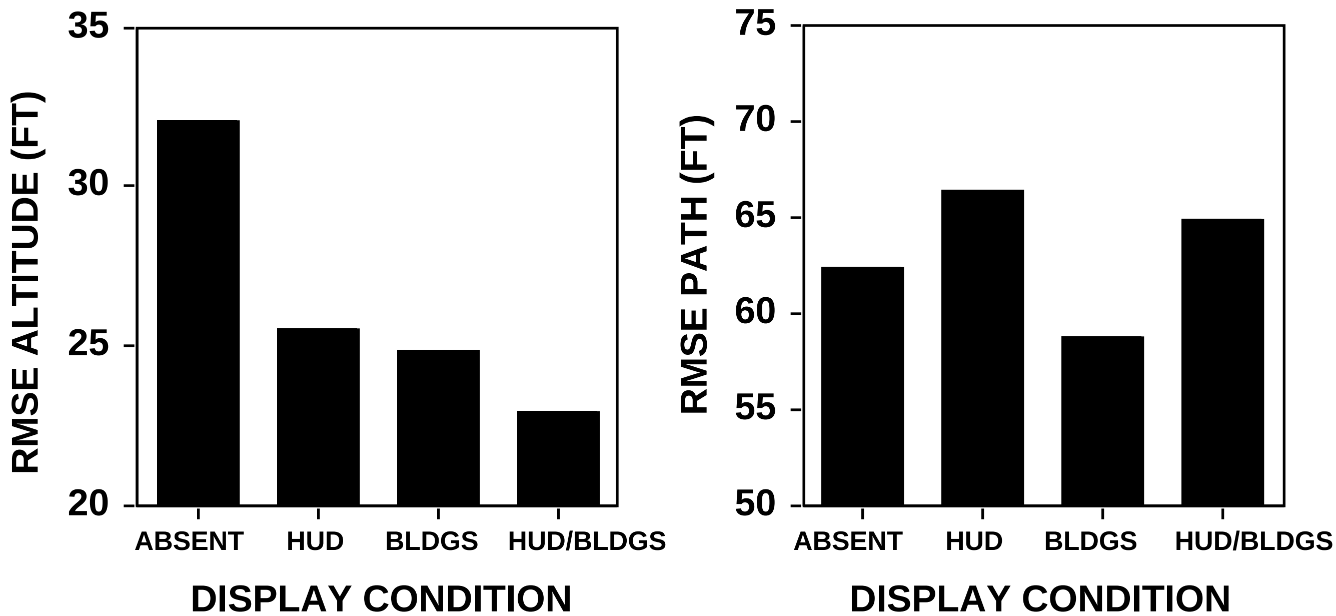

Figure 4. Effects of HUD altitude symbology absence, presence, virtual buildings, and virtual buildings with altitude symbology on RMS Error Altitude (left) and RMS Error Path (right).

recent experiment examined the effect of scene-linking on Foyle et al.'s (7) altitude/path performance tradeoff (the finding that in a part-task simulation of helicopter flight, superimposing a digital altitude indicator improved altitude maintenance performance, but impaired path following performance). In addition to the standard condition involving the superimposed digital altitude symbol, we included a condition in which "virtual" buildings were added to both sides of the path at regular intervals. Each building was exactly 100 feet in height, the assigned maintenance altitude. The two panels in Figure 3 illustrate the various cues to altitude supplied by the buildings. In the left panel, the vehicle is at 100 feet, and is flush with the tops of the buildings. Additionally, as determined by the visual geometry, the tops of the buildings are coincident with the horizon line. In the right panel the vehicle is below 100 feet, so the buildings now extend above the horizon. Thus, the buildings provide a number of high quality visual cues to altitude.

5.1.1. *Results*

The results are presented in Figure 4. The left panel shows that, as expected, the presence of digital altitude information improved altitude maintenance relative to the control condition. The virtual buildings also improved altitude maintenance, by an amount equal to the digital HUD. The right panel shows that, relative to the control condition, the digital HUD yielded a decrement in path performance, replicating the altitude/path performance tradeoff found in earlier work (Ref 7). However, there was no decrement in path performance with the virtual buildings. The digital HUD was associated with an altitude/path performance trade-off, but the scene-linked HUD was not.

5.1.2. *Discussion*

These results demonstrate that scene-linked symbology can be just as effective as traditional forms of superimposed symbology when it comes to providing information. This follows from the fact that the improvement in altitude maintenance associated with the virtual buildings was equal to the improvement associated with the digital HUD. Unlike the digital HUD, however, the virtual buildings did not produce a decrement in path following. At a theoretical level, this result suggests that scene-linking the altitude cues enabled concurrent processing of HUD symbology and information in the far domain. At a practical level, the result supports our contention that scene-linked HUDs provide a design solution for performance problems associated with attentional capture.

5.2. Experiment 2: Scene-linking versus ease of processing

Although the buildings experiment was informative, it left an important question unresolved. The path-following component of the flight task was based on perceived distance between the helicopter and the tops of the pyramids - an analog form of computation. Similarly, when altitude cues were provided by the

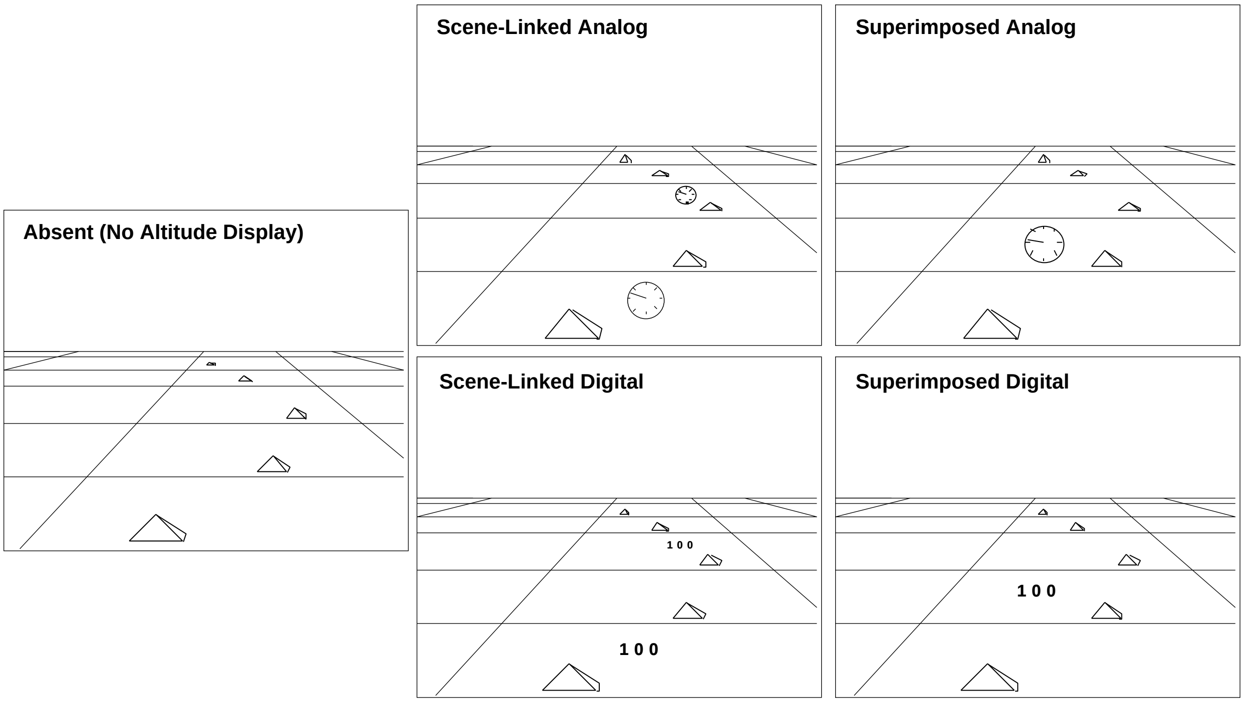

Figure 5. Schematic drawings (not to scale) of the five HUD symbology conditions (as labeled).

virtual buildings, altitude maintenance was based on the perceived distance between the vehicle and the tops of the buildings - also an analog computation. However, when the altitude cue took the form of a superimposed digital HUD, altitude maintenance was based on a digital computation. Scene-linking was thus confounded with the form of the altitude information. In general, analog displays are thought to be easier to process than digital displays; analog information is extracted more intuitively, it maps more directly onto the response system (i.e., analog control inputs), and it requires fewer mental transformations. Thus, it is not clear from the experiment whether the virtual buildings improved concurrent processing of the HUD symbology and the far domain because the buildings were scene-linked, or because they provided altitude information in a form that was easier to process than digital information.

We recently completed an experiment to discriminate the scene-linking account from the different format account (Foyle, McCann, & Shelden, Ref 19). One test involved a scene-linked version of the digital altitude indicator, where the digital readout was converted to a virtual object and interleaved with the pyramids (illustrated in Figure 5). On the one hand, if parallel processing of the superimposed digital HUD and the path was discouraged because of difficulty processing digital information, the same difficulty should be present when the digital symbology is scene-linked. Consequently, the altitude/path performance trade-off found with the superimposed symbol should be preserved. On the other hand, if parallel processing was prevented due to superimposed symbology capturing visual attention, then the scene-linked version should enable parallel processing, just as the scene-linked buildings did. Therefore, the altitude/path performance tradeoff should disappear.

The other test required an analog symbol for altitude that could be either scene-linked or superimposed. These criteria were satisfied by a "clockface" containing a pointer to current altitude (Figure 5). When the helicopter was flying at exactly 100 feet, the pointer was at the 9 o'clock position. Deviations below 100 feet caused the pointer to rotate in a counter-clockwise direction; hence, as the helicopter descended, the pointer rotated downward. Similarly, deviations above 100 feet caused the pointer to rotate clockwise, in an "up" direction. As with the digital altitude display, this analog display was presented either superimposed (Figure 5; top right panel), or as a scene-linked virtual object interleaved with the pyramids.

The predictions are straightforward. If the altitude/path performance tradeoff found in earlier studies (Ref 7) was due to greater difficulty processing digital than analog display formats, the tradeoff should be

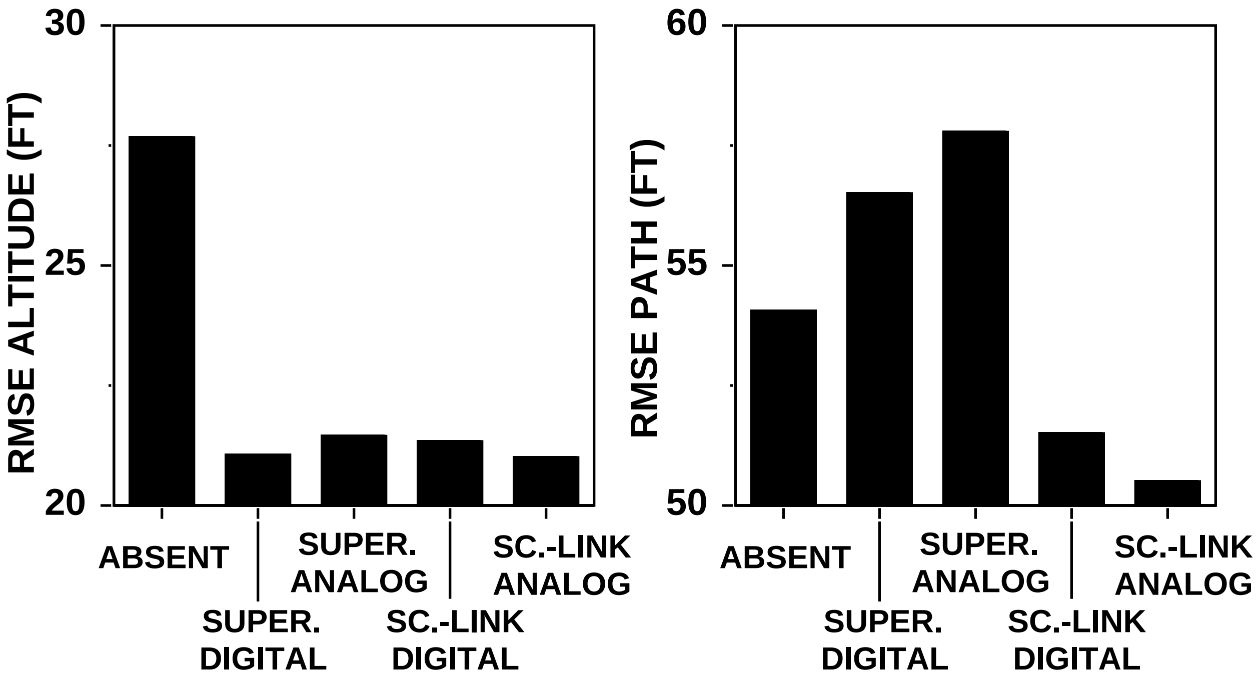

Figure 6. Results of experimental test: Effects of HUD altitude symbology absence, superimposed digital symbology, superimposed analog clock symbology, scene-linked digital symbology and scene-linked analog clock symbology on RMSE Altitude (left) and RMSE Path right).

eliminated by the clockface altitude display, regardless of whether the display is superimposed or scene-linked. Alternatively, if scene-linking is the critical factor, then the performance tradeoff should be present when the clockface is superimposed on the forward scene, but not when the clockface is scene-linked.

5.2.1. *Results*

The results are summarized in Figure 6. Starting with altitude maintenance (left panel), we see that, relative to the control condition, all of the altitude displays yielded better performance. Statistical analyses confirmed this observation, and also revealed that the magnitude of the benefit was the same for all displays. We conclude, therefore, that the clockface display was just as useful a guide to altitude as the digital display. The right panel shows that, relative to the control condition, the improvement in altitude maintenance was accompanied by an increase in path following error for the superimposed versions (both digital and analog formats). This replicates the altitude/path performance tradeoff found in previous experiments. In sharp contrast, the scene-linked displays (both analog and digital) yielded a significant *decrease* in path error.

5.2.2. *Discussion*

The results can be summarized as follows. An altitude/path performance tradeoff was present when the altitude display was superimposed on the far domain, but not when the display was scene-linked. This was true regardless of whether the form of the altitude display was digital or analog. We infer from this pattern that scene-linking produced the performance benefits obtained in the buildings experiment, not the change in display format that accompanied scene-linking.

One aspect of the results deserves additional comment. This is the fact that, relative to the control condition, the scene-linked altitude displays not only afforded an improvement in altitude maintenance, but also in path maintenance. The latter result may be due to the fact that the scene-linked displays, being interleaved with the pyramids, increased the number of reference points against which to gauge the helicopter's current position relative to the path. Regardless of the source of the benefit, it illustrates an important point. As well as promoting parallel processing of superimposed symbology and the far domain, scene linked symbology can enhance or augment flight-relevant information in the far domain. Thus, scene-linking offers not one, but two opportunities to enhance performance.

6. IMPLICATIONS AND FUTURE DIRECTIONS

Design solutions are only useful insofar as the technology is available to implement them. We should note that certain components of a scene-linked HUD are already in place, in the form of fully conformal

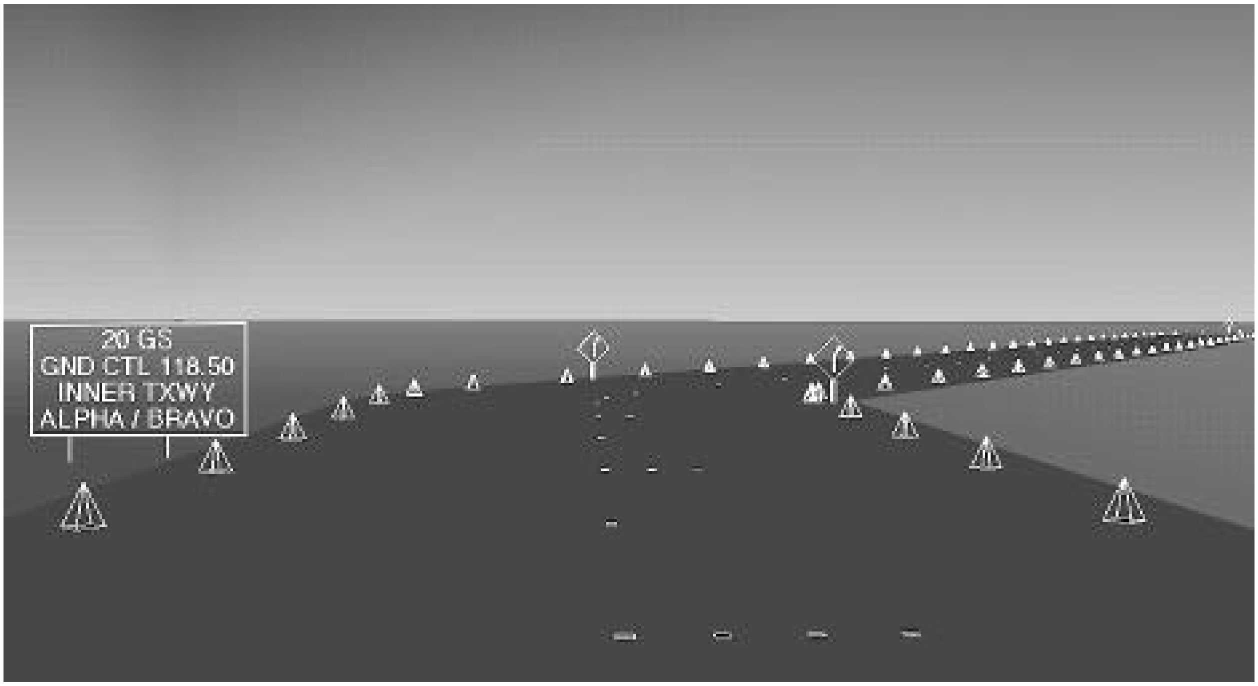

Figure 7. Scene-linked HUD symbology for taxi and surface operations. Symbology (shown in white) includes Virtual Instruments (billboard aircraft instrumentation and location information) and virtual Scene Augmentations (edge cones, turn signs and "countdown" warnings).

runway outlines. The technology necessary to generate this and other scene-linked symbology requires an advanced display media, such as a holographic HUD, a highly accurate positioning system, and a visual database. Today, positioning systems are only available at airports equipped with precision radar facilities. In the near future, however, satellite-based positioning systems (GPS) will bring accurate positioning capability to virtually all aircraft. As GPS systems saturate the marketplace, there is no technical reason why scene-linked HUDs could not preliferate along with them.

Our research suggests that scene linking superimposed symbology abolishes performance problems associated with attentional capture. If designed appropriately, scene-linking can also improve performance on tasks, such as guidance and navigation, that are based on far-domain information. These features should make scene-linked symbology particularly useful in three environments. One is nap-of-the-earth helicopter flying, where rapid switching between the instruments and the out-the-window scene is a constant requirement. Another is low visibility approaches, since pilots are focusing on primary flight display symbology, but must at the same time be sensitive to runway incursions, other air traffic, and ground traffic. The third is low visibility taxi operations. Enhancing or augmenting far domain information with scene-linked symbology could lead to faster and more efficient taxi operations, and perhaps even enable taxi operations under low visibility, where none are permitted today. The development of low-visibility scene-linked HUD symbology for airport taxi is currently underway at NASA, and is discussed below.

6.1. **Scene-linked taxi symbology**

Surface operations are a particularly attractive option for scene-linked HUDs. Currently, surface operations are one of the least technologically sophisticated components of the air transport system. Pilots are given little or no explicit information about their current position, and routing information is limited to ATC communications and airport charts. Under low visibility conditions, pilots can become spatially disoriented, leading to time-consuming interactions with ATC and reductions in taxi speed. Figure 7 illustrates a candidate scene-linked HUD symbology taxi display to alleviate the problems. The symbology contains two types of scene-linked information: virtual instruments (aircraft communication information and current location displayed on a virtual "billboard"), and scene augmentations (taxiway edge markers pictorially augmenting the scene).

The virtual billboard to the left of the taxiway includes aircraft communication status information and ground location. The top line contains the aircraft's current ground speed (20 KTS, "20 GS"). This is a dynamic readout and would change as appropriate. Similarly, the ground billboard represents the aircraft's current airport location. The "Current, Last/Next" format represents current runway or taxiway segment ("Inner Taxiway"), the last intersection passed ("Alpha"), and the next intersection upcoming ("Bravo"). The example shows that this aircraft is on the Inner Taxiway, past Alpha, and before Bravo.

The pictorial scene augmentations shown include visual information that would aid the pilot in following the taxiway clearance and completing turns. Vertical side cones on the side of the commanded taxiway path depict the ATC cleared route on the HUD in superimposed symbology (as in "Pink 5" at Chicago O'Hare). The cones are conformal and represent a virtual representation of the cleared taxi route on the HUD. Both the cones and the centerline markings are shown repeated every 50 feet down the taxiway. The vertical development and constant spacing should yield increased capability for estimating ground speed, drift, and look-ahead capability for turns (see Denton, Ref 20; Johnson & Awe, Ref 21). Turn "countdown" warnings are shown in which each turn has countdown (4, 3, and 2) centerline lights that are (300, 200, and 100 feet, respectively) before each turn. This gives added distance cues for the turn. The virtual turn signs (with the arrows) give an added cue to the turn. In addition, the angle of the arrow on the sign represents the true angle of the turn (i.e., 30 deg right for a 30 deg right turn). All of the HUD symbology is scene-linked, enabling the pilot to process the symbology and still retain awareness of other traffic, including possible incursions. This and other candidate scene-linked HUDs are currently under test in a high-fidelity part-task simulator at NASA.

7. CONCLUSION

This article has reviewed recent research on superimposed symbology in the Flight Management and Human Factors Division at NASA-Ames Research Center. The message from our work cam be summarized as follows. Human information processing abilities are severely constrained by attentional limitations. These limitations must be taken into consideration when evaluating the costs or benefits of a particular display device. In the present case, we have seen that superimposing symbology on the pilot's forward field of view is necessary but not sufficient to support simultaneous processing of instrument information and far domain information. Concurrent processing can be achieved, however, with scene-linked symbology.

8. ACKNOWLEDGMENTS

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9. REFERENCES

1. Naish, J. M. (1964). Combination of information in superimposed visual fields. *Nature*, *202*, 641-646.

2. Lauber, J. K., Bray, R. S., Harrison, R. L., Hemingway, J. C., & Scott, B. C. (1982). *An operational evaluation of head-up displays for civil transport operations* (NASA Technical Paper 1815). Moffett Field, CA: NASA Ames Research Center.
3. Fischer, E., Haines, R. F., & Price, T. A. (1980). *Cognitive issues in head-up displays*. NASA Technical Paper 1711, NASA Ames Research Center, Moffett Field, CA.

4. Weintraub, D. J., Haines, R. F., & Randle, R. J. (1984). The utility of head-up displays: Eye-focus versus decision time. *Proceedings of the 28th Annual Meeting of the Human Factors Society* (pp. 529-533). Santa Monica, CA: Human Factors Society.

5. Wickens, C. D. & Long, J. (1995, in press). Object vs. space-based models of visual attention: Implications for the use of head-up displays. *Journal of Experimental Psychology*: *Applied*.

6. Brickner, M. S. (1989). Apparent limitations of head-up displays and thermal imaging systems. In R. S. Jensen (Ed.), *Proceedings of the Fifth International Symposium on Aviation Psychology* (pp. 703-707). Columbus, OH: The Ohio State University.

7. Foyle, D. C., McCann, R. S., Sanford, B. D., & Schwirzke, M. F. J. (1993). Attentional effects with superimposed symbology: Implications for head-up displays (HUD). *Proceedings of the 37th Annual Meeting of the Human Factors and Ergonomics Society* (pp. 1340-1344). Santa Monica, CA: Human Factors and Ergonomics Society.

8. Iavecchia, J. H., Iavecchia, H. P., & Roscoe, S. N. (1988). Eye accommodation to head-up virtual images. *Human Factors, 30,* 689-702.

9. Fischer, E. (1979). *The role of cognitive switching in head-up displays*. NASA Contract Report 3137). Moffett Field, CA: NASA Ames Research Center.

10. Kahneman, D., & Henik, A. (1981). Perceptual organization and attention. In M. Kubovy & J. Pomerantz (Eds.), *Perceptual Organization* (pp. 181-211). Hillsdale, NJ: Erlbaum.

11. Duncan, J. (1984). Selective attention and the organization of visual information. *Journal of Experimental Psychology: General, 113*, 501-517.

12. McLeod, P., Driver, J., Dienes, Z., & Crisp, J. (1991). Filtering by movement in visual search. *Journal of Experimental Psychology: Human Perception and Performance, 17*, 55-64.

13. Yantis, S. (1992). Multielement visual tracking: Attention and perceptual organization. *Cognitive Psychology*, *24*, 295-340.

14. Rock, I., & Gutman, D. (1981). The effect of inattention on form perception. *Journal of Experimental Psychology: Human Perception and Performance*, *7*, 275-285.

15. McCann, R. S., Foyle, D. C., & Johnston, J. C. (1993). Attentional limitations with Head-Up Displays. In R. S. Jensen (Ed.), *Proceedings of the Seventh International Symposium on Aviation Psychology* (pp. 70-75). Columbus, OH: The Ohio State University.

16. McCann, R. S., Lynch, J. M., Foyle, D. C., & Johnston, J. C. (1993). Modeling attentional effects with Head-Up Displays. *Proceedings of the 37th Annual Meeting of the Human Factors Society* (pp. 1345-1349). Santa Monica, CA: Human Factors Society.

17. McCann, R. S., Johnston, J. C., Foyle, D. C., & Lynch, J. M. (1993, November). *Shifting attention between visual domains: Evidence from Head-Up Displays*. Paper presented at the 34th annual meeting of the Psychonomics Society, Washington, D. C.

18. Foyle, D. C., Ahumada, A. J., Larimer, J., & Sweet, B. T. (1992). Enhanced/synthetic vision systems: Human factors research and implications for future systems. *SAE Transactions: Journal of Aerospace*, *101*, 1734-1741.

19. Foyle, D. C., McCann, R. S., & Shelden, S. (1995, in press). Attentional issues with superimposed symbology: Formats for scene-linked displays. In R. S. Jensen (Ed.), *Proceedings of the Eighth International Symposium on Aviation Psychology*. Columbus, OH: The Ohio State University.

20. Denton, G. G. (1980). The influence of visual pattern on perceived speed. *Perception, 9*, 393-402.

21. Johnson, W. W., & Awe, C. A. (1994). The selective use of functional optical variables in the control of forward speed. NASA Technical Memorandum 108849. Moffett Field, CA: NASA.