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# Attentional Issues in Superimposed Flight Symbology

**David C. Foyle**
**NASA Ames Research Center**
**Moffett Field, CA 94035**

**Beverly D. Sanford**
**San Jose State University**
**San Jose, CA 95192**

**Robert S. McCann**
**Sterling Federal Systems**
**NASA Ames Research Center**
**Moffett Field, CA 94035**

Superimposed symbology on head-up displays (HUDs) and panel- or helmet-mounted displays of sensor imagery has proven to be a useful tool for decreasing pilot workload and aiding the pilot in assimilating information. Superimposed symbology allows the pilot to spend more time "eyes out", retaining both aircraft and world awareness. The symbology may be superimposed on a direct vision view of the world (via transparent electronics as in a HUD), on sensor information (as for the AH-64 Apache Helicopter), or on a graphics version of the world (e.g., the synthetic vision system proposed for the High-Speed Civil Transport). The head-up display (HUD) uses the technique of placing symbology collimated at optical infinity in the pilot's field-of-view. This allows pilots to access both the out-the-window view of the world and onboard aircraft displays in the same region of fixation and accommodation. Without a HUD pilots have to move their eyes and refocus to view the outside world and the instruments. Pilots reports that they have found the HUD to be an extremely useful display. Scientific studies, as well, have demonstrated various advantages of HUD over non-HUD designs (e.g., Weintraub, Haines & Randle, 1984).

In the early stages of HUD design, however, a human factors flaw surfaced: Fischer, Haines and Price (1980) noted occasions when pilots failed to attend simultaneously to both the HUD symbology information and the outside world information. In their experiment, after many trials of practice using the HUD for landings, an aircraft unexpectedly moved onto the runway from the taxiway. Pilots continued their landing as if the intrusive aircraft was not there, suggesting that they were no longer monitoring the visual scene upon which the HUD was superimposed.

In a US Air Force report, McNaughton (1985) described a similar problem in an operational situation: Experienced pilots engaged in flight exercises lost situational awareness while using HUDs. That is, the pilots lost awareness of the pitch and roll angle of the aircraft and the direction of the ground despite the fact that the information displayed on the HUD was in their direct line-of-sight.

Roscoe (1987) has suggested that these failures occur because HUDs cause pilot's accommodation to move inwards toward the resting dark focus level away from the optimal infinity focus. This focus change, he argues, is the mediating factor in the reported problems. Roscoe's argument, however, does not explain a recent finding by Brickner (1989), who demonstrated the failure to process simultaneously outside world information and HUD symbology information with a non-collimated graphics display (i.e., both the symbology and the out-the-window view were displayed at identical optical distances). Brickner's study simulated a rotorcraft flight task. Subjects flew a slalom course in which they were to avoid pylon hits, misses of the gaps between pylons, and to maintain a constant

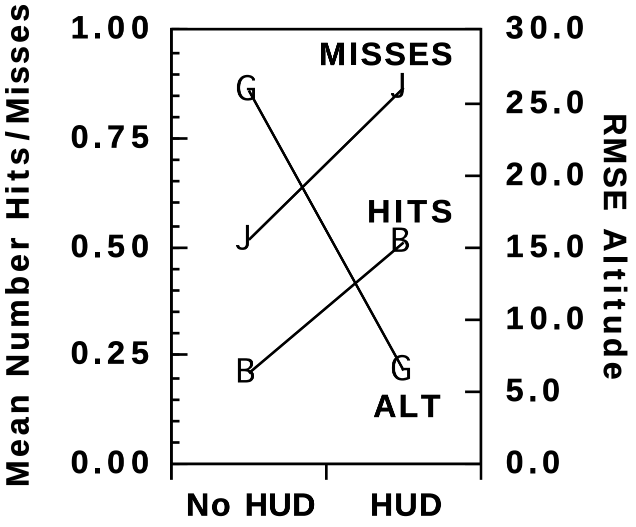

Figure 1. Brickner (1989) data: Slalom course hits, misses and RMSE Altitude with and without HUD.

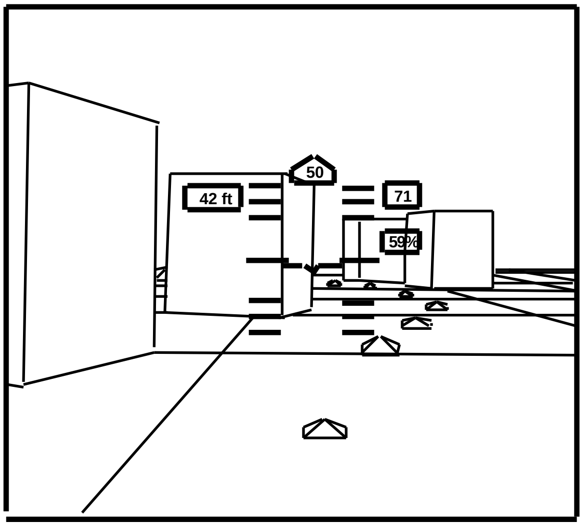

Figure 2. Schematic display of simulation showing ground grid, path, HUD and buildings (high-pictorial condition).

altitude (given by the out-the-window perspective, as well as digitally on the HUD symbology). As shown in Figure 1, Brickner found a tradeoff between slalom course and altitude control performance: Digital HUD altitude information yielded more accurate altitude maintenance, but with increased pylon hits and slalom gap misses. Without digital HUD altitude information, altitude maintenance was poor, but slalom course performance was improved.

A possible explanation of these results might be pilots' inability to process both world and HUD information due to ineffective division of attention. People are very poor at dividing attention between two separate objects in the visual field (Duncan, 1984; Treisman, Kahneman & Burkell, 1983). The Gestalt principles of perceptual organization, similarity of form, and common fate, as well as color, have been identified as allowing separate objects to unify into a single, wholistic object, or to segregate into separate objects (Kahneman & Henik, 1981). The Gestalt principles of perceptual organization may force the HUD display to attentionally segregate from the out-the-window scene behind it. The information displayed on the HUD tends to be fairly homogeneous, with respect to color and form, but quite different from the characteristics of the world scene. Further, the relative motion of the world relative to the HUD may augment this separation. These factors may segregate the HUD and the world into different "attentional objects" causing a divided attention deficit.

Another, clearly related explanation has been posed to explain similar findings (Bennett, 1991). It is also the case that the "frame-of-reference" of the HUD and the world differ. The HUD display is physically and perceptually coupled to the aircraft, whereas the out-the-window scene is world referenced. The HUD/world divided attention deficit might be explained by the cognitive processing required when the pilot changes frames of reference. It is not clear, however, whether the two mechanisms (i.e., object segregation vs. frame-of-reference) make differential performance predictions.

The goal of the present research was to test the attentional deficit account of the HUD-induced performance problems identified above. To this end, we first sought to replicate the HUD/out-the-window performance tradeoff found by Brickner (1989). A replication with non-collimated displays would provide further evidence that the deficit is not due to visual accommodation effects. Additionally, we assessed the effect of providing altitude information in a format that was integrated into the world, as opposed to being on the HUD. Therefore, conditions were included in which buildings in the simulation were as tall as the assigned altitude. This created a highly salient visual cue for altitude maintenance that was world referenced rather than HUD/aircraft referenced.

The predictions from the attention deficit hypothesis are as follows. If subjects have difficulty dividing attention between the HUD and the world, HUD-induced improvements in altitude performance should be associated with poorer path performance (i.e., replicating Brickner, 1989). If, in addition, subjects use the tops of the buildings as an "out-the-window" altitude cue, altitude performance should be improved by the presence of the buildings. However, since buildings are world referenced, there should be no attentional deficit associated with their use. Thus, building-related improvements in altitude performance should not tradeoff with flight path performance.

## METHOD

### Subjects

Eight male college-age subjects, reporting normal or corrected normal vision, were paid to participate in the experiment.

### Flight Simulation and Experimental Conditions

The flight task was implemented on a Silicon Graphics 3130 workstation and displayed on a high-resolution 19-in color monitor. Flight was controlled via a spring-centered joystick, with a viewing distance of 65 cm. A simple tracking algorithm determined control of the simulated aircraft. The joystick sampling, data collection, and all graphics were updated at 12 Hz.

A 2x2x2x4x2 factorial design was used with conditions: HUD altitude information (present or absent); pictorial altitude information (high or low); simulated forward velocity (110 kts or 80 kts); path (4 flight paths); and, replications (two). In the simulation, ground structure included a grid and small pyramids (24 ft x 24 ft x 6 ft vertical) spaced at 330 ft intervals, indicating the flight path to be flown. The low-pictorial information condition consisted of flight with a ground grid and small pyramids determining the path. The high-pictorial information condition consisted of the grid, the pyramids, and twelve buildings (200 ft x 200 ft x 100 ft vertical), placed along the path at a distance of 230 ft. The assigned altitude of 100 ft was level with the building rooftops. The four paths consisted of two 660 ft segments, two 1320 ft segments, and two 1980 ft segments connected by six 330 ft segments (in various orders). Each segment required a turn of 30, 45, or 60 degrees. Buildings were placed on the obtuse side of all turns. The HUD display was centered on the screen, and consisted of an artificial horizon, pitch ladders, speed, thrust, and digital altitude (in feet) information. The altitude data was the only relevant HUD information in the flight and was 0.8 cm x 0.4 cm (for a 3-digit value) in size. The altitude information was centered 6.5 cm to the left and 3.0 cm up from the center of the screen. Figure 2 shows a schematic of the display with the HUD present and high-pictorial information.

### Procedure

Testing required one 3.5 hr session. Subjects were given verbal instructions followed by a demonstration of the flight task by the experimenter. The subject's task was to maintain an altitude of 100 ft, and to fly directly over the flight path. As in the Brickner (1989) study, subjects were explicitly instructed to attend equally to the altitude and flight path tasks, and that both were equally important. Vertical and lateral wind buffeting was present at all times during the flight and was simulated by a sum of sines algorithm. Each flight started with the aircraft in line with the first leg of the flight at a distance 10 sec from the beginning of the flight path at the assigned 100 ft altitude. During the 10-sec warm-up period, there was no buffeting and no data were collected.

Subjects flew 16 practice flights under all conditions (although not with all possible assignments of flight path to conditions). These practice flights were not analyzed. Subjects were informed of the conditions prior to each flight. Data were collected on 64 experimental flights. Feedback, in the form of lateral deviation from the ground path and from the assigned 100 ft altitude (RMSE), was given verbally and visually.

## RESULTS

Separate univariate analyses of variance were conducted on the root mean squared error (RMSE) Altitude and RMSE Path data. Figure 3 shows that the presence of a HUD facilitated altitude maintenance performance (F(1,7) = 5.98, $p < .05$), but led to poorer performance on the path (F(1,7) = 6.30, $p < .05$). High-pictorial information significantly improved altitude performance (F(1,7) = 5.39, $p = .05$), but had no effect on path performance (F(1,7) < 1). The interaction of Pictorial information and HUD presence for RMSE Altitude (Figure 3, left panel) was not significant (F(1,7) = 3.35, $p = .11$).

Other statistically significant factors included: RMSE Path was larger for the slow velocity than the fast (F(1,7) = 6.02, $p < .05$); RMSE Path decreased on the second replication (F(1,7) = 10.94, $p = .01$); and the interactions of pictorial x velocity x path x replication were significant (RMSE Altitude: F(3,21) = 3.40, $p < .05$; RMSE Path: F(3,21) = 4.82, $p = .01$).

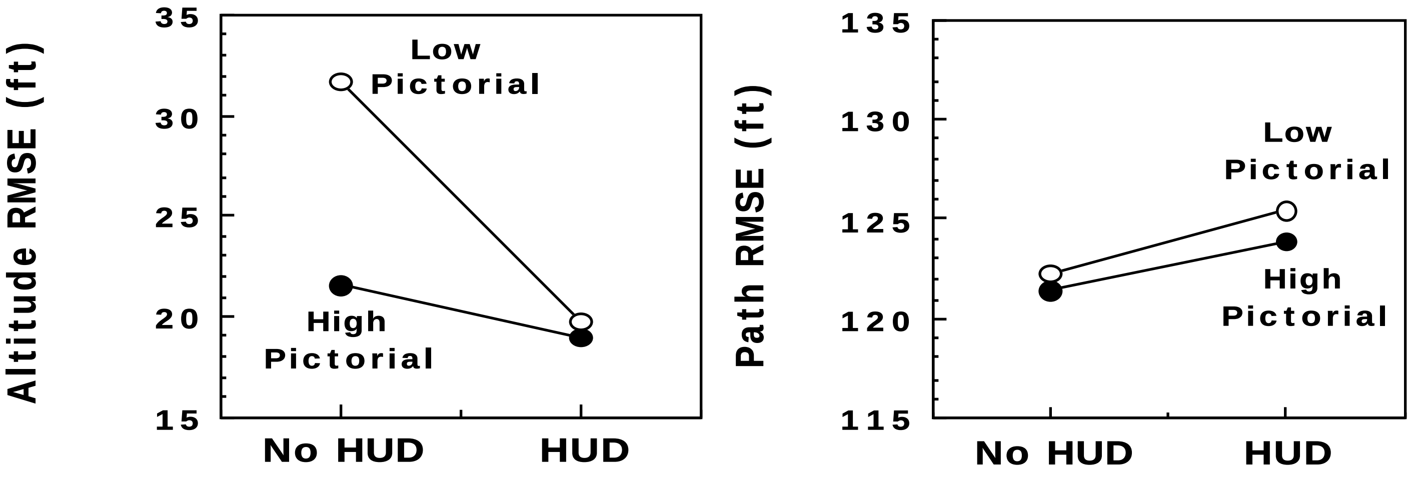

Figure 3. RMSE Altitude (left panel) and RMSE Path (right panel) as a function of low- and high-pictorial condition and HUD presence/absence.

## DISCUSSION

The presence of digital altitude information in HUD superimposed symbology facilitated the maintenance of altitude at a preassigned level, but also yielded poorer performance on the flight path which required monitoring the visual scene behind the HUD. Thus, the experiment replicated the HUD/world performance tradeoff reported by Brickner (1989). The high-pictorial altitude information condition yielded an important new finding: Highly salient, out-the-window, altitude information (i.e., the high-pictorial condition) improved altitude maintenance, but without an associated cost on flight path performance. The data indicate, however, that even in the high-pictorial condition, the presence of the HUD information still interfered with path performance; subjects were not able to ignore completely the HUD information (as seen by the absence of a pictorial main effect, and the absence of a significant pictorial x HUD interaction for RMSE Path).

These effects are consistent with the theory that information with different frames of reference, or alternatively, from attentionally segregated objects, cannot be processed in parallel, but must be time-shared. This was shown in the performance tradeoff between the HUD altitude information (aircraft referenced) and the path information (world referenced). When the two information sources shared a common frame of reference, or were from attentionally integrated objects, parallel processing without cost was possible. This was seen in the high-pictorial conditions, in which both the altitude information (building rooftops) and the path information were world referenced.

## SUMMARY AND IMPLICATIONS

The mechanisms of the failure to simultaneously process HUD superimposed symbology and the out-the-window scene may reside in the many cognitive and perceptual cues that tell the pilot that the HUD, although collimated at infinity, is an instrument on the aircraft. That is, relative to the world scene, the HUD forms a perceptually segregated object that has a different frame of reference. Research is underway to explore further the mechanisms involved in this problem, and to develop advanced designs which maximize the cognitive and perceptual compatibility of the superimposed symbology by integrating the important information into the world scene. One candidate design for heading and pitch information is to use a virtual grid reference system that would be overlaid on the entire world (as if attached to the world) including the sky. A similar system projected onto the ground plane only has proven useful as a flight tool (Bennett, O'Donnell & Johnson, 1988). Another candidate design for displayed information is to project it pictorially into the world via superimposed symbology. That is, project the information as if it were being updated on a billboard or on a flight path indicator in the world scene. Information about RNAV waypoints and airport locations, likewise, could be "attached" (virtually) to the actual world to aid geographical orientation and wayfinding. All of these advanced display designs have in common the feature that the superimposed information is referenced to the out-the-window world scene, and not to the aircraft.

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