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Vertical Field of View Reference Point Study for Flight Path Control and Hazard Avoidance

J. Raymond Comstock, Jr., Marianne Rudisill, Lynda J. Kramer, and Anthony M. Busquets
Langley Research Center, Hampton, Virginia

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Abstract

Researchers within the eXternal Visibility System (XVS) element of the High-Speed Research (HSR) program have developed and evaluated display concepts that will provide the flight crew of the proposed High-Speed Civil Transport (HSCT) with integrated imagery and symbology to permit required path control and hazard avoidance functions while maintaining required situational awareness. The challenge of the XVS program is to develop and demonstrate operationally viable, economically feasible, and potentially certificated concepts that would permit a no-nose-droop configuration of an HSCT and expanded low visibility HSCT operational capabilities. The experiment described herein is one of a series of experiments exploring the "design space" restrictions for physical placement of an XVS display. In this study, the primary experimental issue examined was "conformality" of the forward display vertical position with respect to the side window in simulated flight conditions. "Conformality" refers to the condition such that the horizon and objects appear in the same relative positions when viewed through the forward windows or display and the side windows.

In particular, this study quantified the effects of visual conformality on pilot flight path control and hazard avoidance performance. For this study, conformality related to the positioning and relationship of the artificial horizon line and associated symbology presented on the forward display and the horizon and associated ground, horizon, and sky textures as they would appear in the real view through a window presented in the side window display. The forward display symbology was presented as conformal (i.e., horizon at the same level as the real world view through the side window) or shifted up by 4 or 8 degrees visual angle. The potential incongruities in visual cues associated with nonconformality of the forward display had no significant performance consequences based on testing of six pilots in the NASA Langley Visual Motion Simulator (VMS). Scenarios evaluated included simulated approaches and landings, some with traffic and terrain hazards. No cases of simulator sickness or other physical signs of motion discomfort or vestibular effects were reported for any of the display conditions. Despite no significant negative performance consequences, when asked to rank the display conditions, the preference of five of the six pilots was for the conformal display condition. Factors to take into consideration in interpreting these findings include: (1) a limited vertical field of view (VFOV) of the XVS display due to hardware and experimental constraints, (2) a wide pillar separating the forward display and the side window (about 12 to 15 degrees), (3) the effect of limited vertical field of view on bank angle, (4) all hazards used in the experiment could be described as "slow onset," (sudden, immediate, and large control inputs were not required for hazard avoidance), and (5) all hazard scenarios incorporated good visibility. Subjective ratings and rankings as well as numerous pilot comments are presented.

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Symbols & Abbreviations

ANOVA	Analysis of Variance
CDU	Control and Display Unit
CRT	Cathode Ray Tube
EOG	Electro-oculogram
FOV	Field-of-View
HDD	Head-Down Display
HDOT	Vertical Rate
HSCT	High-Speed Civil Transport
HSR	High-Speed Research
HUD	Head-up Display
TCA	Technology Concept Airplane
TLX	Task Load Index
VFOV	Vertical Field of View
VMC	Visual Meteorological Conditions
VMS	Visual Motion Simulator
XVS	eXternal Visibility System

Introduction

With air travel expected to double in the next five to 10 years, NASA and its U.S. aerospace industry partners are working to develop technologies for a future supersonic passenger jet referred to as the High-Speed Civil Transport (HSCT). As envisioned, this jet would carry 300 passengers at more than twice the speed of sound, with ticket prices only 20 percent over today's comparable slower flights. Technology to make the HSCT possible is being developed as part of NASA's High-Speed Research (HSR) program.

Researchers within the eXternal Visibility System (XVS) element of the HSR program are developing and evaluating information display concepts that will provide the flight crew of the proposed HSCT with integrated imagery and symbology to permit required path control and hazard avoidance functions while maintaining required situational awareness. Researchers are tasked to develop and demonstrate operationally viable, economically feasible, and potentially certificated XVS concepts that would permit a no-nose-droop configuration of an HSCT and expanded low visibility HSCT operational capabilities. (See ref. 1.) The nose-droop mechanism currently used in the British-French Concorde provides the forward visibility required by the flight crew to adequately see the runway during landing and takeoff. The equipment needed to lower and raise the Concorde's nose adds weight and the nose in the lowered (or drooped) position adds drag. To be operationally viable, the HSCT design must be optimized to minimize weight and aerodynamic drag. The weight penalty of a nose-droop configuration for an aircraft the size of an HSCT is roughly estimated to be 10,000 pounds takeoff gross weight. (See ref. 2.) Elimination of a hydraulic-powered mechanical nose on the HSCT by using an external visibility system (that would provide a capability equivalent to the forward facing windows in current commercial transport aircraft) would avoid the weight penalty associated with the nose-droop mechanism. The XVS concept does not have to provide a direct visual replacement for the forward windows, but it must enable the flight crew to perform the required functions of path guidance and hazard avoidance at the same levels provided by forward facing windows. (See ref. 2.)

The XVS will consist of a suite of sensors and supporting systems that will provide the flight crew information that would normally be available in a conventional cockpit through pilot vision in the forward direction. The current XVS concept consists of high-resolution video sensors, high-resolution XVS displays, navigation displays, weather radar with a traffic detection mode, the Traffic Alert and Collision Avoidance System, the Automatic Dependent Surveillance-Broadcast system, Automatic Surface Detection Equipment, and side windows with sunlight control systems. An initial assumption by the XVS element of the HSR program was that the XVS, in combination with any conventional side windows, would provide each pilot with a field of view (FOV) as least as great as the guidelines specified in ARP4101/2. (See ref. 3.) ARP4101/2 is an SAE aerospace standards document detailing the requirements for pilot visibility from the flight deck. To satisfy the criteria of the ARP4101/2 vision envelope, the current display configuration consists of one XVS display each for the pilot and co-pilot, each containing a 40° horizontal and 50° vertical FOV. The XVS display uses 60 pixels per degree (assumed to approach the practical limit of human eye perception). The forward visibility provided by the XVS display is augmented by natural vision through the side windows. (See ref. 4.)

Flight and ground vehicle tests of XVS technologies have been conducted as part of the HSR Flight Deck research project. In 1995, pilots flew approximately 90 approaches and landings from the NASA 737's windowless research cockpit. The pilots were required to control and land the aircraft relying only on sensors and computer-generated images (including various symbols) on the XVS display. This first XVS flight test gave researchers confidence that a future supersonic passenger jet could indeed be flown without forward facing windows in the cockpit.

High priority research issues, like display size and conformality (ref. 5), were identified by researchers within the XVS element. Results from a 1996 XVS flight test (ref. 6) helped define the XVS display size requirements (40° horizontal by 50° vertical FOV). This flight test provided data on the effect of decreasing the inboard FOV by 10º (from 50º to 40º) on pilot path control. Based upon the structural constraints on the HSR Technology Concept Airplane (TCA) flight deck, it may be required that the XVS display be vertically positioned or rotated (in the pitch axis) to fit the space available. This creates a situation such that the forward and side views may be "nonconformal." That is, the horizon and symbology on the XVS display in front may appear to be displaced relative to the real world view from the side window. This conformality displacement may adversely affect pilot flight path and collision avoidance performance.

The experiment described herein is one of a series of experiments exploring the "design space" restrictions for placement of an XVS display. "Design space" refers to the space available for placement of an XVS in the flight deck of an HSCT while accounting for structural constraints. In this study, the primary experimental issue examined was conformality of the forward XVS display vertical position with respect to the side window in simulated flight conditions. In a conformal display, distant display images are displayed at the correct size and location angularly as their real world sources would be if viewed through a window. In particular, this study quantified the effects of visual conformality on pilot flight path control and hazard avoidance performance. For this study, conformality related to the positioning and relationship of the artificial horizon line and associated symbology presented on the forward XVS display and the horizon and associated ground, horizon, and sky textures as they would appear in the real view through a window presented in the side window display. The side window, though computer generated, represented a real window and a view of the real world. For this experiment, the forward XVS display symbology was presented as conformal (i.e., identical to the real world view through the side window) or shifted up by 4 or 8 degrees visual angle.

Due to hardware limitations in the simulator, the forward XVS display used in this experiment had only a 22° vertical FOV at the pilot eye reference point instead of the required 50° vertical FOV as determined by ARP 4101/2. It was not possible to achieve "true" nonconformality by physically repositioning the forward display monitor because of constraints with regard to the physical structure of the simulator. Therefore, nonconformality was created artificially by vertically positioning the "appearance" of the display on the forward monitor. To maintain a consistent vertical FOV across conformal and nonconformal displays, a 14º vertical FOV was chosen. Hence, an 8º shift in the visual angle (22º vertical space available minus fixed 14º vertical FOV) was the maximum amount of nonconformality that could be studied in this experiment.

In the present study, symbology overlaid the forward scene information analogous to

symbology found on Head-up displays (HUDs). HUDs spatially overlay instrument symbols (e.g., a horizon line) conformally with the outside world. In reference 7, Fadden et al. state that several flight simulation studies have demonstrated that conformal HUDs are beneficial when compared to head-down displays (HDDs). It is hypothesized that a conformal XVS display is a more natural way for a pilot to view an external scene as it is comparable to flying heads-up, eyes-out the window. In reference 8, the authors describe some potentially significant human factors problems related to the optical geometric conformality of a display. They state that, "perfect geometric conformality is achieved when the locations of the imaged objects within the virtual space register exactly with the optical locations of the real objects as directly viewed by the observer." The authors describe seven critical geometric display conformality disruptions. The one appropriate for discussion within the context of the current experiment is classified as "display displacement." This geometric conformality disruption exists when the display is not directly in front of the pilot so that the horizon line is not at eye level. The authors warn that the misplacement of the horizon line combined with vestibular cues given by the center of gravity could generate a cue conflict that may lead to physiological side effects particularly for significant longitudinal accelerations or decelerations as they are known to create pitch attitude illusions. If this cue conflict exists, a pilot could have trouble distinguishing between the illusion of pitch attitude due to a misplaced horizon or due to acceleration effects. The authors state that, assuming no large visual/vestibular effects exist, a pilot can often learn to use a nonconformal display effectively.

The primary objective of this simulator experiment was to quantify the effects of visual conformality on pilot flight path control and hazard avoidance performance. Specifically, the hypotheses tested were: (1) Pilot flight control performance and avoidance of airborne hazards will degrade with nonconformal displays as compared to conformal displays due to incongruities in visual and motion cues associated with nonconformality; (2) No differences in pilot flight control performance will be found between motion and non-motion simulator trials, meaning that non-motion simulation facilities could be used in further conformality experiments; and (3) Pilots will prefer conformal XVS displays to nonconformal XVS displays.

To address the second hypothesis concerning the effect of motion cues, all path control trials were conducted under both motion and no-motion conditions. If pilot performance was found to not differ across these motion conditions, then there is no requirement to include motion in future XVS studies, saving time and money and significantly increasing the number of facilities available to support future experiments.

Method

Subjects

Subjects were six transport aircraft-rated pilots (one Captain, five First Officers) recruited under contract by Lockheed-Martin from three airlines: United, American, and USAirways. All subjects were paid for their participation and transportation and lodging expenses were also paid. The number of years flying commercial aircraft that subjects reported ranged from six to 18, with a mean of 9.75 years. Three of the subjects also had experience flying military aircraft (for 10, 20 and 21 years, for the three subjects respectively). The total number of hours flying ranged from a minimum of 3,700 to a maximum of 17,000+, with a mean of 8,540 hours flying. The total number of hours flying as pilot in command ranged from 3,200 to a maximum of 15,000+ hours, with a mean of 5,300 hours. Two of the pilot subjects reported that they had no experience in "glass cockpit" aircraft; three reported one to five years' experience, and one pilot reported six+ years of experience with glass cockpits. The pilot subjects' flight experience and types of aircraft flown are summarized in Appendix A.

Simulator

This experiment was conducted in the NASA Langley Research Center's Visual Motion Simulator (VMS), a generic flight simulator that can be custom-configured for a variety of aircraft-related experiments. The VMS rests on a six degree-of-freedom motion platform and has a flight deck with generic controls and displays. The simulator is outfitted to support research in both transport aircraft and helicopters. The simulation software driving the simulator for this experiment was the HSR Reference H, cycle 2B. This simulation package was chosen as it was already implemented in the VMS and also incorporated a baseline HUD that only required slight modifications to the symbology in order to serve as the XVS display (primary flight display) described below.

For this experiment, pilot subjects sat in the left seat and the experimenter sat in the right seat during experimental trials. The repositionable left seat is equipped with a sidestick controller (for pitch and roll control) and conventional rudder pedals (for yaw control) with toe brakes. The sidestick controller rests on the left armrest of the left seat. A four-lever throttle quadrant (with a back-driven autothrottle), a Control and Display Unit (CDU), and gear/flap levers are located on the console between the left and right seats. During experiment trials, the autothrottle was in operation and only the left-most two of the four throttle levers were used. A photograph of the VMS cockpit interior (pilot side) is shown in Figure 1.

The VMS has two forward windows and two side windows, each with a wide-angle collimated display providing out-the-window views. Collimation is achieved via commercially available systems that utilize a mirror-beam-splitter arrangement (See Figure 2). The total FOV of the forward display from the left seat is 40 degrees vertically and 50 degrees horizontally. The out-the-window scenes are computer-generated images (CGI) created by an Evans & Sutherland graphics engine. The images are constructed from database information; for this experiment, the out-the-window views were of the Denver International Airport area.

The XVS concept was used as the primary flight display in this experiment and contained guidance elements and basic flight condition information. The XVS symbology was overlaid onto the computer generated out-the-window scene which, in turn, was displayed to the pilot on the collimated forward window display. The specific XVS symbology chosen for display in this experiment is shown in Figure 3. A detailed description of the original HSR Reference H model and associated baseline HUD symbology can be found in Reference 9. A sidestick XVS symbology decluttering button permitted removing some, all, or none of the overlaid XVS symbology.

The HDD's presented airspeed, altitude, and vertical speed on traditional round dial instruments. A CRT display presented Attitude/Pitch information, while engine performance was shown on round dial indicators.

The VMS XVS software was modified to accommodate this experiment. The forward images were electronically masked and also shifted upward to produce the conformality/ non-conformality display conditions which are described in detail in the next section.

Figure 1. Visual motion simulator cockpit interior.

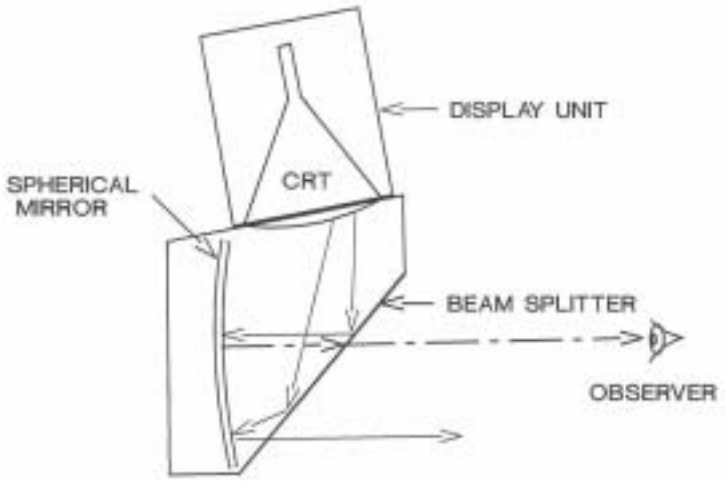

Figure 2. Optical collimation system based upon a mirror-beam-splitter arrangement.

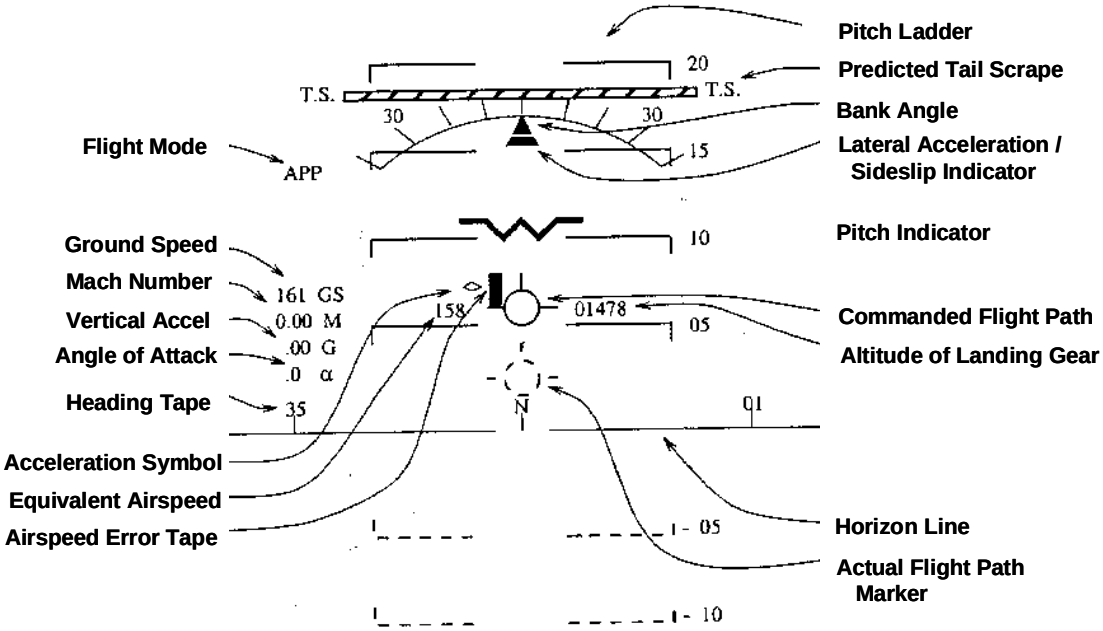

Figure 3. XVS symbology.

Display Conformality/Nonconformality

When the world is viewed during flight through an aircraft flight deck's front and side windows, the views are the same. That is, the horizon appears in the same position in both views; when this occurs, the view may be said to be "conformal." With the XVS system, the real world information that is displayed is provided through the integration of synthetic, sensor, and camera-based inputs. Based upon the structural constraints on the HSR Technology Concept Airplane (TCA) flight deck, it may be required that the XVS display be vertically positioned or rotated (in the pitch axis) to fit the space available. This creates a situation such that the forward and side views may be "nonconformal." That is, the horizon and symbology on the XVS display in front may appear to be displaced relative to the real world viewed from the side window. This "conformality displacement" may adversely affect pilot flight path and collision avoidance performance. There is no guidance from the research literature that relates to possible effects of display conformality/nonconformality on pilot performance. Therefore, the present study was designed to address this issue and to provide a "reference point" with regard to pilot performance under conformality and varying degrees of nonconformality. In particular, these studies explored restrictions on the design space of the XVS by evaluating vertical displacements of the XVS display and assessing the impact of the created nonconformality on pilot performance. Conformality/nonconformality created by vertical displacement of the display monitor is depicted in Figure 4.

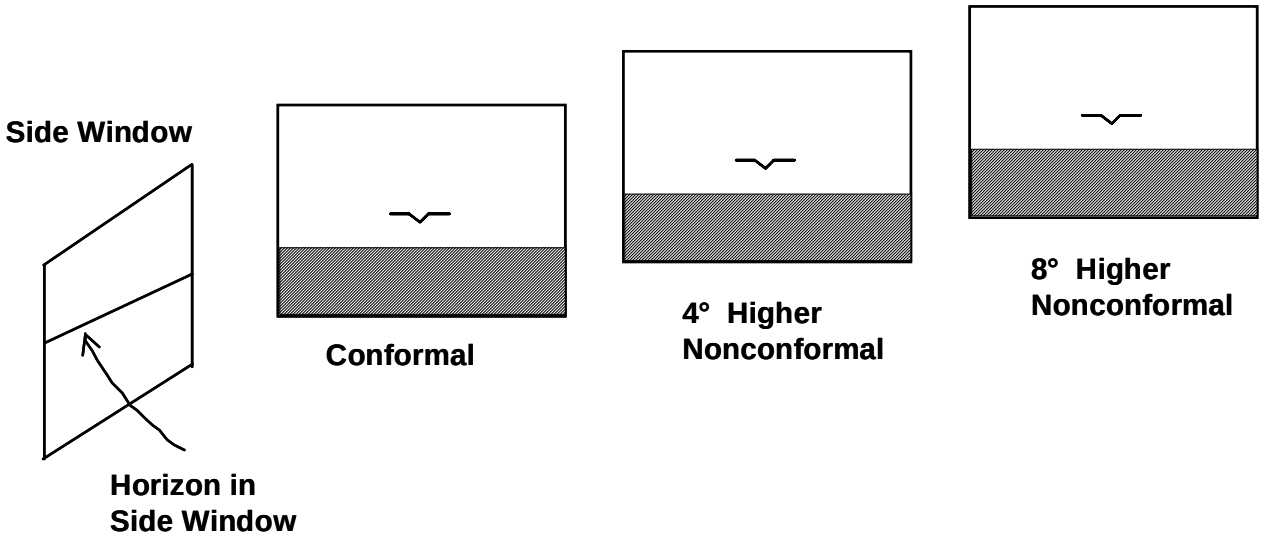

Figure 4. Conformality created through vertical displacement of the display monitor.

There were four conformality/nonconformality display conditions in this study. These conditions are summarized in Table 1 and graphically depicted in Figure 5. In the present experiment, it was not possible to achieve "true" nonconformality by physically repositioning the forward display monitor because of constraints with regard to the physical structure of the simulator. Therefore, nonconformality was created artificially by vertically positioning the

"appearance" of the display on the forward monitor. Two vertical shifts to simulate nonconformality were chosen for exploration in the present study: four degrees and eight degrees.

In addition, the total vertical display area of the forward monitor was 40º, but at the pilot design reference point, the vertical field of view (VFOV) subtended an angle of 22º, with 7º devoted to the image of the ground at the base of the display area. For consistency, a ground display area of 7º was maintained across all displays. To achieve this, an opaque black mask was placed across the bottom of both the 4º and 8º nonconformal displays.

As the image was shifted vertically (by 4º or 8º) to achieve nonconformality and the mask was placed at the bottom of the display, the total VFOV became shortened (for a VFOV of 18º and 14º for the 4º and 8º nonconformal shifts, respectively). This confounded the effects of nonconformality and VFOV. That is, the non-conformal displays were both nonconformal and had a shortened VFOV relative to the conformal display. To maintain a consistent VFOV across conformal and nonconformal displays, a 14º VFOV was maintained by placing a black mask across the top of the display (if required to maintain a 14º VFOV). This created three display types, all with a 7º ground area and a 14º VFOV: (1) conformal, (2) 4º nonconformal, and (3) 8º nonconformal.

The masks significantly reduced the possible VFOV. Pilot performance may be affected by nonconformality or by a significantly reduced VFOV. To examine the effects of nonconformality independent of the reduced VFOV, a fourth display condition was created such that the display was at maximum non-conformality (i.e., 8º), but the display was not masked, allowing the pilots a full view of the display area. In this display condition, the total VFOV was 22º, the maximum VFOV allowable.

Table 1. Conformality/Nonconformality Display Conditions

Conformality Condition	**Vertical Displacement (degrees)**	**Vertical Field of View (degrees)**
(1) Conformal	0	14
(2) Nonconformal 4 deg	4	14
(3) Nonconformal 8 deg	8	14
(4) Nonconformal 8 deg+	8	22

Scenarios

In the present study, multiple scenarios were created to assess the effects of conformality/ nonconformality on pilot obstacle and terrain collision avoidance performance. In some scenarios, the pilot is required to control the aircraft while following another aircraft; in other scenarios, an obstacle (another aircraft) is unexpected; and in another scenario, the task is to avoid collision with terrain. These scenarios are summarized in Table 2 at the end of this section. There were four types of scenarios: (1) Flight Path Control, (2) Hazard Avoidance, (3) Terrain Avoidance, and (4) Training

Flight Path Control and Hazard Avoidance Scenarios

To assess pilot *flight path control* performance, two "base" scenarios were created that required the pilots to perform multiple flight path control maneuvers (the differences in the two scenarios did not allow direct comparison of pilot performance across the scenarios). Both "base" scenarios required the pilot to perform turns during which the horizon appeared to traverse (from the pilot's viewpoint) from one window to the other (that is, front window to side window or side to front).

To assess *hazard avoidance*, variants were created from each of the two "base" scenarios. There were two scenario sets, each set composed of a "base" scenario (for *flight path control* assessment) and its variants (for *hazard avoidance* assessment).

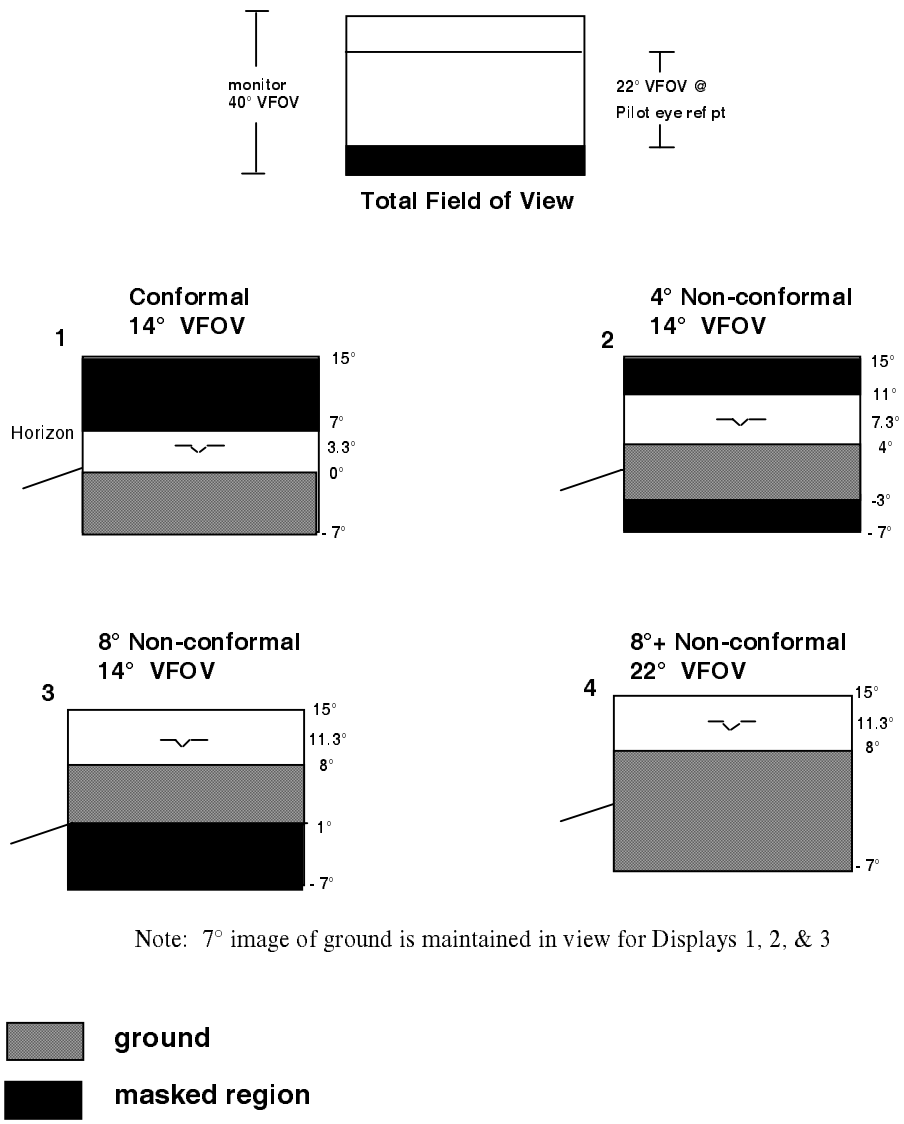

Figure 5. Conformality/nonconformality displays with vertical fields of view.

Scenario Set A:

- Scenario 1: The first "base" scenario (Scenario 1), created to assess *flight path control* performance, required pilot subjects to follow a lead aircraft to a landing and make several left turns while following the lead aircraft, continuing through touchdown, landing on Rwy 35L, and runway turnoff. On initiating the scenario, the pilot's aircraft was positioned 7.6 nautical miles from the runway, at an altitude of 2000 feet and with an airspeed of 155 knots. (See Figure 6 for a graphical depiction of Scenario 1.)

Variants of "base" Scenario 1 to assess *Hazard Avoidance*:

- Scenario 2: In Scenario 1, the pilot was required to follow the lead aircraft, making several left turns, then land on Rwy 35L. In Scenario 2, the initial conditions were identical to those in Scenario 1 and the pilot was required to perform the same maneuver, bringing the aircraft in-trail behind the lead aircraft. However, on first turning to come in-trail behind the lead aircraft, a second aircraft 300 feet below Ownship in-trail behind the lead aircraft is encountered. The pilot is required to perform an avoidance maneuver to avoid the second in-trail aircraft (see Figure 7).

- Scenario 3: In Scenario 1, the pilot was required to follow the lead aircraft, making several left turns, then landing on Rwy 35L. In Scenario 3, the initial conditions were identical to those in Scenario 1 and the pilot was required to perform the same maneuver, bringing Ownship in-trail behind the lead aircraft. However, on first turning to come in-trail behind the lead aircraft, the lead aircraft slows speed. The pilot is required to perform an avoidance maneuver to avoid the lead aircraft (see Figure 8).

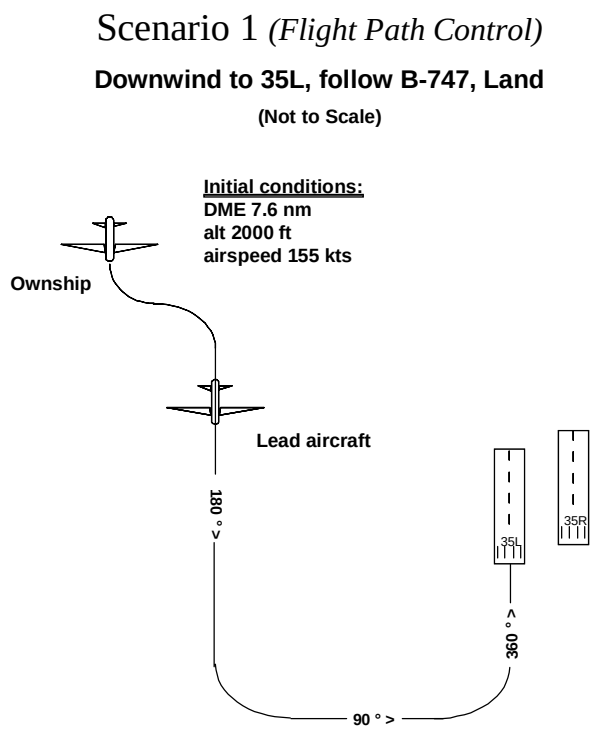

Figure 6. Scenario 1 (*Flight Path Control* evaluation).

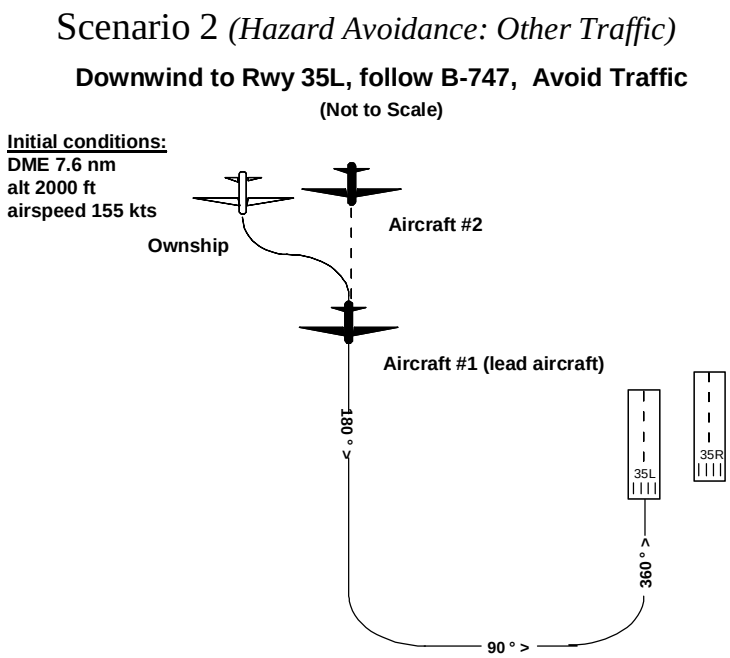

Figure 7. Scenario 2 (*Hazard Avoidance* evaluation): a variant of Scenario 1.

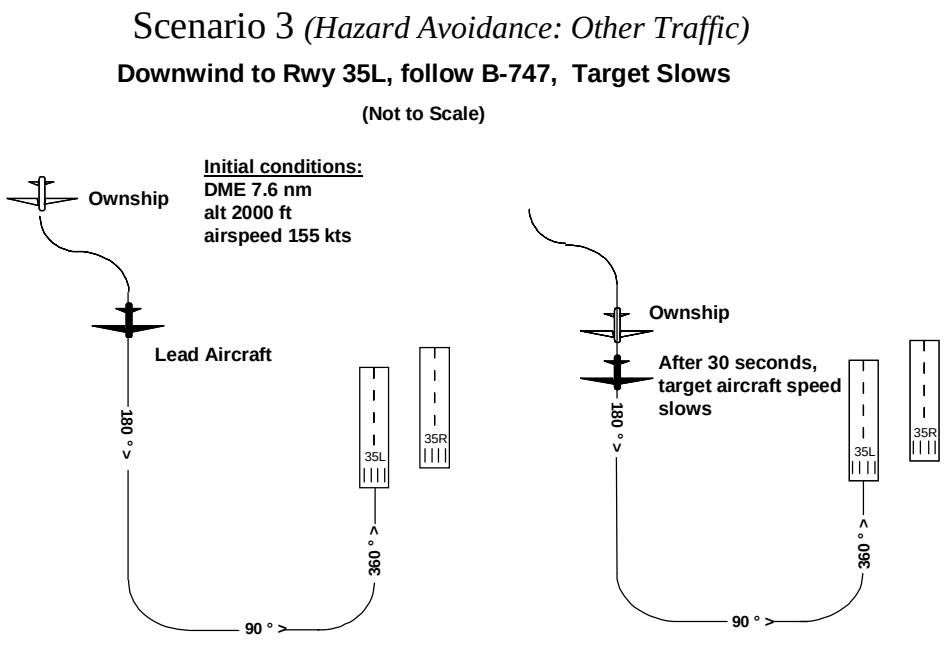

Figure 8. Scenario 3 (*Hazard Avoidance* evaluation): a variant of Scenario 1.

Scenario Set B:

- Scenario 4: The second "base" scenario (Scenario 4) to assess *flight path control* performance required pilot subjects to perform a landing with a four-mile straight-in final approach to Rwy 35L, with a small transport aircraft on the left, and a large transport aircraft on the right landing on Rwy 35R. The scenario continued through landing on Rwy 35L and runway turnoff. The pilot's aircraft ("Ownship") was initially at a distance of 4.7 nautical miles from the runway and at an altitude of 1500 feet, with an airspeed of 155 knots. The aircraft on the left (small transport) was initially a distance of 4 nautical miles from the runway, climbing at 2,000 feet, with an airspeed of 155 knots. (See Figure 9 for a graphical depiction of Scenario 4.)

  Variant of "base" Scenario 4 to assess *Hazard Avoidance*:

- Scenario 5: In Scenario 4, the pilot was required to perform a landing with a four-mile straight-in final approach to Rwy 35L, with two parallel transport aircraft (one on the right, landing on Rwy 35R, and one on the left). To assess *hazard avoidance*, in Scenario 5, the transport aircraft on the right performs an excursion to the left, crosses the Ownship flightpath and heads to land on Rwy 35L. Go-around instructions are immediately given to the pilot subject by ATC (to climb to an altitude of 1500 feet and turn to a heading of 330) and the pilot subject is required to perform the maneuver to avoid the right aircraft (see Figure 10).

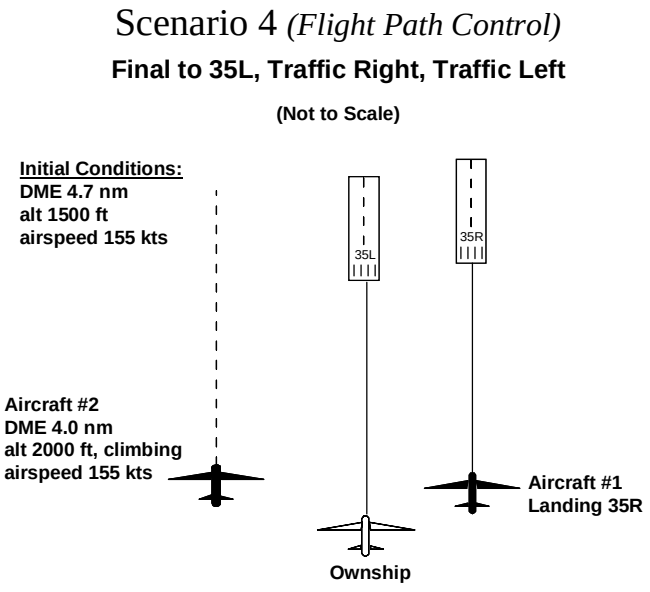

Figure 9. Scenario 4 (*flight path control* evaluation).

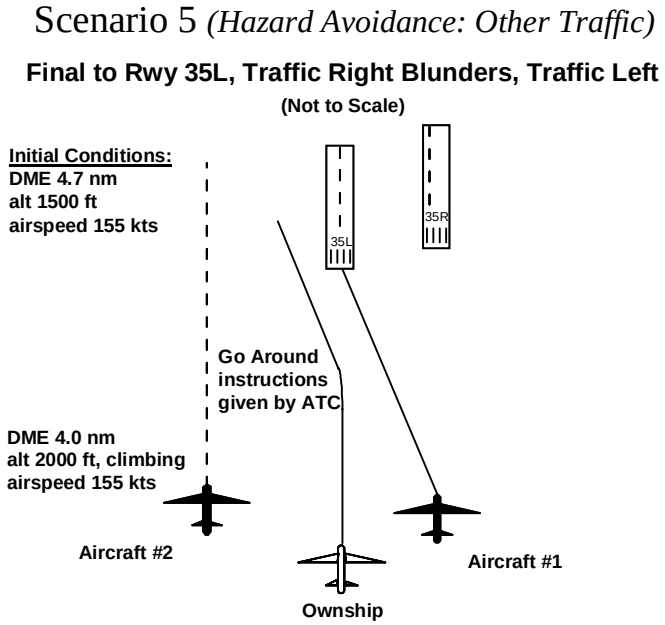

Figure 10. Scenario 5 (*Hazard Avoidance* evaluation): a variant of Scenario 2.

Therefore, five scenarios were created to assess pilot *flight path control* and *hazard avoidance* performance, organized into two sets: Scenario Set A consisted of a base scenario (Scenario 1) and two variants of this base (Scenarios 2 and 3), and Scenario Set B consisted of a base scenario (Scenario 4) and a variant of this base (Scenario 5).

Terrain Avoidance Scenario

In addition, a sixth scenario was created to assess pilot *terrain avoidance* performance under conformality and nonconformality display conditions. This scenario (Scenario 6) was initiated with the pilot subject's aircraft at an altitude of 6,000 feet, an airspeed of 155 knots, and a heading of 340º, flying above a mountainous area with mountain ridges both to the left and right. The pilot was instructed to turn to a heading of 270º, toward the left mountain ridge, and fly above the ridge, maintaining an altitude of 500 feet above the ridge (see Figure 11).

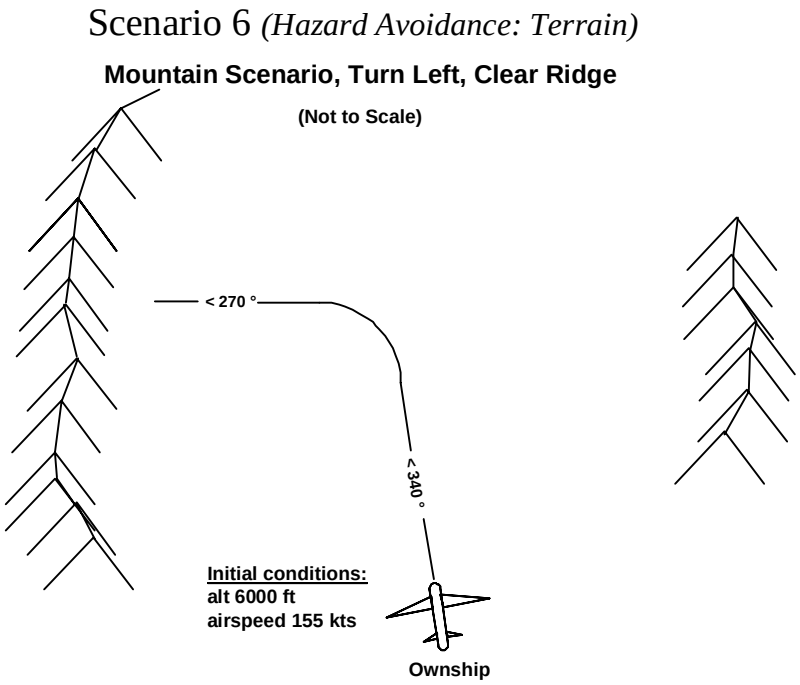

Figure 11. Scenario 6 (Terrain Avoidance evaluation).

Training Scenarios

Prior to having the pilot subjects perform the Flight Path Control, Hazard Avoidance, and Terrain Avoidance scenarios, they were trained on several aspects of the aircraft simulation, the experiment procedures, and the data collection protocol. The training trials also provided the pilot subjects landing and flare practice (see the Procedures section for a detailed description of the training process). Two scenarios were developed specifically for this training.

The first training scenario (Training Scenario 1) began at 500 feet altitude and the pilot subjects were required to perform a straight-in final approach and landing on Rwy 35L. The second training scenario (Training Scenario 2) was initiated at 1500 feet altitude and approximately five miles out on the base leg, and the pilot subjects were required to turn onto final and complete the landing on Rwy 35L. Training Scenarios 1 and 2 are given in Figures 12 and 13.

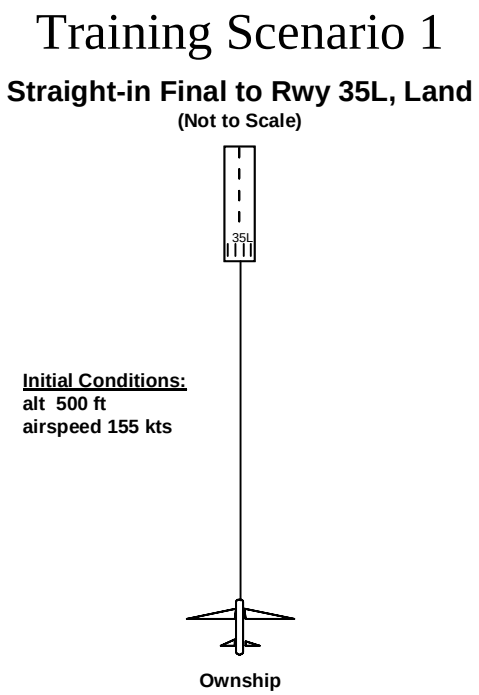

Figure 12. Training Scenario 1.

Training Scenario 2

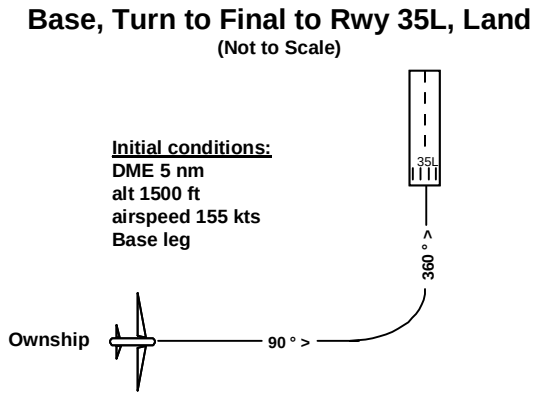

Figure 13. Training Scenario 2.

Table 2. Summary of Flight Path Control, Hazard Avoidance, Terrain Avoidance, and Training Scenarios

Scenario Number and Type	Scenario Description	Performance Evaluated
Scenario Set A:		
(1) Base Scenario	Follow lead a/c through turns to landing	Flight Path Control
(2) Variant of Scenario 1	Follow lead a/c through turns to landing; avoid aircraft in-trail behind lead aircraft	Collision Avoidance (other traffic)
(3) Variant of Scenario 1	Follow lead a/c through turns to landing; when in-trail, avoid lead aircraft which slows airspeed	Collision Avoidance (other traffic)
Scenario Set B:		
(4) Base Scenario	Four-mile straight-in final to Rwy 35L; small transport on left; large transport on right landing on Rwy 35R	Flight Path Control
(5) Variant of Scenario 4	Four-mile straight-in final to Rwy 35L; small transport on left; avoid large transport on right making excursion across flight path to land on Rwy 35L	Collision Avoidance (other traffic)
Terrain Avoidance		
(6) Base Scenario	Fly through valley between mountains; turn left, fly over top of ridge, climb to clear ridge top, level-off, maintain 500 foot altitude over ridge	Collision Avoidance (terrain)
Training		
Training Scenario 1	Straight-in Final to Rwy 35L, land	None
Training Scenario 2	Base, turn to Final to Rwy 35L, land	None

Experiment Design

Independent Variables

Flight Path Control and Hazard Avoidance Evaluation. The flight path control and hazard avoidance evaluation was a 4 x 2 x 6 (Conformality x Motion x Subjects) factorial design using two sets of scenarios (A and B). Each trial involved manipulating the type of display conformality while performance data were collected as pilot subjects flew pre-defined scenarios. Each trial consisted of a unique combination of conformality, motion, and scenario. The evaluation design is summarized in Table 3.

For each of the two sets of scenarios (A and B), the base scenarios were conducted under both motion and no motion conditions, while the variant scenarios were conducted with motion only. That is, for Scenario Set A, pilot subjects performed Scenario 1 under motion and no motion conditions, while Scenarios 2 and 3 were conducted only with motion. For Scenario Set B, Scenario 4 was conducted under motion and no motion conditions, while Scenario 5 was conducted under motion only.

In addition, trials were replicated. The base scenario trials (Scenarios 1 and 4) received three replications (to allow direct comparisons of pilot performance across both Motion and No Motion conditions of these specific flight control evaluations) and the remaining scenario trials (Scenarios 2, 3, and 5) received two replications each. All six pilot subjects performed all trials across all scenarios, conformality types, and motion conditions. Therefore, there were a total of 24 trials for each base scenario (4 conformality types x 2 motion conditions x 3 replications) and a total of nine trials for each of the three variant scenarios (4 conformality displays x 1 motion condition x 2 replications**).**

Table 3. Experiment Design: Flight Path Control and Hazard Avoidance Performance Evaluation

Factor	**Factor Levels**	**Description of Factor Levels**
(1) Conformality Type	4	Conformal 22 Degrees VFOV 4 deg Non-conformal 14 deg VFOV 8 deg Non-conformal 14 deg VFOV 8 deg Non-conformal 22 deg VFOV
(2) Motion/No Motion	2 1	Motion/No Motion (Scenarios 1 & 4) Motion only (Scenarios 2, 3, & 5)
(3) Subjects	6	Six transport pilots
(4) Replications	3 2	Base scenario (Scenario 1) Hazard Avoidance scenarios (Scens 2, 3, & 5)

Terrain Avoidance Evaluation. The terrain avoidance performance assessment was carried out only under motion conditions, with one trial at each of the four conformality/ nonconformality display conditions with no replications. All terrain avoidance trials were

performed by all of the six pilot subjects. Therefore, the terrain avoidance evaluation was a 4 x 6 factorial design (Conformality x Subjects) having a total of four trials for each subject (4 conformality displays x motion x no replications). This design is summarized in Table 4.

Table 4. Evaluation Design: Terrain Avoidance Evaluation (Scenario 6)

Factor	**Levels of Factor**	**Description of Factor Levels**
(1) Conformality Type	4	Conformal 22 Degrees VFOV 4 deg Non-conformal 14 deg VFOV 8 deg Non-conformal 14 deg VFOV 8 deg Non-conformal 22 deg VFOV
(2) Subjects	6	Six transport pilots

Dependent Measures

A detailed list of all dependent measures is given in Appendix B. Several types of *objective* data were automatically collected on all trials to indicate experimental evaluation condition (e.g., scenario number, conformality condition), the aircraft state, and the pilot subject's performance. Aircraft state data were collected at variable rates; data were recorded at 1 Hz [cycles per second] from the start to the end of the simulator run and at 20 Hz from five nm to touchdown.

Aircraft state data collected included: aircraft position; aircraft attitude; indicated airspeed; distance to other aircraft; lateral and vertical path error; pitch, roll, and sink rates; controller input angles; rudder pedal position; throttle position; and engine power.

In addition, some aircraft state measures were taken as single event measures at touchdown. At first gear touchdown, aircraft position, elapsed time, sink rate, lateral velocity, and indicated airspeed were recorded. At nosewheel touchdown, aircraft position, elapsed time, lateral velocity, and pitch rate were recorded.

In addition to aircraft state measures, both heart rate and electro-oculogram (EOG) data were recorded for the pilot subjects. Heart rate was recorded by an unobtrusive earclip plethysmo-graph and EOG was recorded by a unobtrusive sensors mounted on skin adjacent to the eye to detect "left looks."

Several *subjective* measures were also taken at selected points throughout the experimental trials. These measures were in the form of the NASA TLX instrument for estimating perceived workload, preference rankings of the conformal/nonconformal displays taken at one time at the end of all experimental data collection runs, and a questionnaire constructed to subjectively compare display "usability" across conformality conditions. All test sessions were also videotaped.

Trials

All Training, Flight Path Control, Hazard Avoidance, and Terrain Collision Avoidance trials are summarized in Table 5.

Training. During training trials, the pilot subjects were required to fly the two training scenarios, giving them basic practice in handling and landing the aircraft. Subjects flew four initial training trials with the conformal display (two trials with each of the two training scenarios), then four trials at each of the four conformality conditions (two with each training scenario). All training trials were conducted with no motion. This totaled 20 training trials, ten with each of the two training scenarios (eight with the conformal display [0º] and four each with the non-conformal displays [4º, 8º, 8º+]).

Flight Path Control and Hazard Avoidance. The flight path control/hazard avoidance evaluations required the pilot subjects to fly the scenarios at all four conformality display conditions. Within each evaluation, a single simulator trial involved a unique combination of scenario, motion, and conformality; a trial was replicated either two or three times, depending on the scenario type.

In evaluating performance with Scenario Set A, the pilot flew Scenarios 1, 2 and 3. Pilot subjects flew the base scenario (Scenario 1), both with motion and no motion with three replications, and the hazard avoidance scenarios (Scenarios 2 and 3) with motion only and with two replications (to reduce the total number of trials).

In evaluating performance with Scenario Set B, the pilot subjects flew Scenarios 4 and 5. Subjects flew the base scenario (Scenario 4), both with motion and no motion with three replications, and the collision avoidance scenario (Scenario 5) with motion only and with two replications (again, to reduce the total number of trials).

Also, it was particularly important to assess the impact of conformality display type on performance on the first trial involving an “unexpected” hazard avoidance situation (i.e., with Scenarios 2, 3, and 5). Therefore, a single extra trial of each “collision avoidance” type was embedded in the set of trials where they were first encountered for each subject. Therefore, there is one extra trial of each of these three hazard avoidance scenario conditions.

Therefore, for Scenario 1, this resulted in a total of 12 Motion (4 conformality x 3 replications) trials and 12 No Motion (4 conformality x 3 replications) trials. There were nine trials for Scenario 2 (4 conformality x 2 replications + one extra trial for the first hazard avoidance trial) and nine trials for Scenario 3 (4 conformality x 2 replications + one extra trial for the first hazard avoidance trial). Therefore, this provides a total of 24 Scenario 1 trials, and nine trials each for Scenarios 2 and 3, totaling 42 trials when evaluating pilot subject performance with Scenario Set A.

Following the same pattern, the performance evaluation with Simulation Set B resulted in a total of 12 Motion (4 conformality x 3 replications) trials and 12 No Motion (4 conformality x 3 replications) trials for Scenario 4. Scenario 5 had a total of nine trials (4 conformality x 2 replications + one extra trial for the first hazard avoidance trial). Therefore, this provided a total

of 24 Scenario 4 trials and nine Scenario 5 trials, totaling 33 when evaluating pilot subject performance with Scenario Set B.

Terrain Avoidance. This evaluation required the pilot subjects to fly Scenario 6 only. This was carried out under Motion only, with one trial at each of the four Conformality conditions, creating a total of four Terrain Avoidance trials.

Table 5. Summary of Trials by Evaluation Condition, Scenario Set, Motion, Conformality, and Replications.

Experiment and Scenario	**Motion**	**Conformality Condition**	**Replications**	**Number of Trials**
Training				
Initial Training: Training Scenario 1 Training Scenario 2	 No Motion No Motion	 0º 0º	 2 2	 2 2
Training Scenario 1	No Motion	0º, 4º, 8º, 8º+	2	8
Training Scenario 2	No Motion	0º, 4º, 8º, 8º+	2	8
TOTAL Number of Trials				20
Flight Path Control & Hazard Avoidance (Other Traffic) Evaluation				
Scenario Set A				
Base scenario (Scenario 1)	Motion No Motion	0º, 4º, 8º, 8º+ 0º, 4º, 8º, 8º+	3 3	12 12
Collision Avoidance (Scenario 2)	Motion	0º, 4º, 8º, 8º+	2	8 (+1)
Collision Avoidance (Scenario 3)	Motion	0º, 4º, 8º, 8º+	2	8 (+1)
TOTAL Number of Trials				42
Scenario Set B				
Base scenario (Scenario 4)	Motion No Motion	0º, 4º, 8º, 8º+ 0º, 4º, 8º, 8º+	3	12 12
Collision Avoidance (Scenario 5)	Motion	0º, 4º, 8º, 8º+	2	8 (+1)
TOTAL Number of Trials				33
Terrain Collision Avoidance				
Scenario 6	Motion	0º, 4º, 8º, 8º+	None	4
TOTAL Number of Trials				4
TOTAL Experimental Trials				79

Organization of Trials

A typical order of all trials for one pilot subject is given in Appendix C.

Training Session. Pilot subjects received a total of 20 training trials, ten with each of the two training scenarios. The first four trials were conducted using the conformal display condition (for initial familiarization). The remaining 16 trials were blocked by conformality and given in the order (1) conformal, (2) 4 degree nonconformal, (3) 8 degree nonconformal, and (4) 8+ degree nonconformal, with four trials at each conformality condition (two with each of the two training scenarios).

Flight Path Control and Hazard Avoidance (Other Traffic) Evaluations. All Flight Path Control and Hazard Avoidance (Other Traffic) Evaluations using Scenario Sets A and B were conducted separately. Within both sets of evaluations, trials were blocked by Motion (with three of the subjects receiving all Motion trials first, followed by No Motion trials, and the other three subjects receiving the opposite order). Within both evaluations, trials were also blocked by conformality (0º, 4º, 8º, 8º+) and the orders of conformality trial blocks were counterbalanced across subjects (ordering was determined using a balanced 4 x 4 Latin Square).

For evaluations with Scenario Set A, Scenarios 1, 2, and 3 trials were randomized within a conformality block. Therefore, with Scenario Set A, pilot subjects received a total of 12 Scenario 1 trials under the No Motion condition, blocked by and counterbalanced across conformality. Under Motion, subjects received 12 Scenario 1 trials, 9 Scenario 2 trials, and 9 Scenario 3 trials, blocked by and counterbalanced across conformality.

For evaluations conducted with Scenario Set B, Scenarios 4 and 5 trials were randomized within a conformality block. Subjects received a total of 12 trials with Scenario 4 under the No Motion condition, blocked by and counterbalanced across conformality. Under the Motion condition, they received 12 Scenario 4 trials and 9 Scenario 5 trials, blocked by and counterbalanced across conformality.

Terrain Avoidance Evaluation. Subjects received the four Scenario 6 trials in one block, with the ordering of the four conformality conditions counterbalanced across subjects (with ordering determined by a 4 x 4 Latin Square).

Procedure

Pilot subjects were run individually across two days. Upon arriving on Day One, the subject completed a pilot background questionnaire (providing such information as aircraft type ratings and years as a professional pilot) and signed an Informed Consent form, a Physiological Measures Informed Consent Form, and a High-Speed Research Program non-disclosure agreement. Subjects were then given a brief description of the experiment and its purpose.

Training for the experiment then began. Subjects were brought to the Vertical Motion Simulator and were introduced to all aspects of the simulator flight deck's operation. They first received training on the use of the side-arm controller, the XVS symbology and its use, flap settings, and engine controls. They were then introduced to special handling characteristics of

the HSCT aircraft model. Subjects were then permitted to fly four trials (two of each of the two training scenarios) with the conformal display. Upon completing these initial trials, the four conformality displays and conditions were described and subjects flew four trials (two of each of the two training scenarios) at each of the four conformality display conditions.

Therefore, subjects flew a total of 20 training trials (ten of each of the two training scenarios), four initial trials with the conformal display and four at each of the four conformality display conditions. Upon completing these training trials, the experimenter answered the subject's questions and the subject was then given a ten-minute break while the VMS was configured for the first set of experimental trials.

After the break, the heart rate monitor and EOG electrodes were attached and calibrated and subjects were then reseated to perform the Flight Path Control and Hazard Avoidance experimental trials. Half of the subjects performed the motion trials first, followed by the no motion trials while the other half of the subjects performed these trials in the reverse order. As noted earlier, within a block of motion or no motion trials, the trials were also blocked by conformality, such that subjects received a set of trials at one conformality display type. After completing each block of trials with one conformality display, subjects completed the TLX and usability questionnaire for that specific display. They then performed the next set of conformality display trials, followed by the TLX and usability questionnaire. This procedure continued until all experimental trials, TLX ratings, and usability questionnaires were completed within one motion/no motion block (resulting in a total of four TLX ratings and four usability questionnaires).

After performing the first set of Flight Path Control and Hazard Avoidance experimental trials, the subject was given a ten-minute break during which the VMS was configured for the second set of experimental trials, then the experimental trials resumed. Prior to performing the second set of experimental trials, a single trial was given using the first training scenario. This was followed by the full set of remaining Flight Path Control and Hazard Avoidance experimental trials. Within this set of trials, subjects again completed the TLX and usability questionnaire after each set of trials at each of the four conformality displays (resulting in four additional completed TLX and usability questionnaires, for a total of eight of each type). The subject was then given a ten-minute break and the VMS was configured for the four Terrain Collision Avoidance trials. After completing the Terrain Collision Avoidance trials, subjects were asked to verbally rank (1 through 4) the four types of conformality displays. After the ranking, Day One data collection was completed.

On Day Two, the subject was reminded of the experimental task and was given practice with two trials with the first training scenario. The subject then received the first set of Flight Path Control and Hazard Avoidance trials. Half of the subjects received the motion trials first, followed by the no motion trials and half the subjects received the trials in the reverse order. As during Day One, within each set of motion/no motion trials, the trials were blocked by conformality display condition. After each set of conformality displays, the subject again completed the NASA TLX and usability questionnaire. After performing all of the first set of experimental trials, the subject was then given a ten-minute break during which the VMS was configured for the remaining experimental trials. The subject then received the last set of experimental trials, again completing the NASA TLX and usability questionnaire after each set

of conformality display types. The subject was then debriefed, paid, and released for the day.

Results

Objective Data Analyses

Analyses were conducted on the objective aircraft state and pilot subject state variables noted in Appendix B for both Flight Path Control and Hazard Avoidance performance evaluations (Scenarios 1 and 4). To maximize the sensitivity of these variables, many were analyzed for specific portions or times within the approach and landing task. One specific portion or time of interest was during turns, because turns involved looks from the forward display to the side window display and back, a time during which changes in display conformality might most affect task performance. Summaries of Analysis of Variance (ANOVA) statistical procedures are presented in Table 6 for turn 2 (downwind to base turn) and Table 7 for turn 3 (base to final turn). No significant differences were found in any of the task performance measures for either conformality condition or simulator motion or their interaction. Specific variables examined included altitude maintenance, bank angle standard deviation, maximum bank angle reached, and distance to target aircraft. In terms of objective measures of operator behavior, no significant differences were found for heart rate or for number of “looks” or transitions from the forward to side window displays. One exception was the “left looks” during turn 3 (base to final turn) where there was a significantly greater number of “left looks” for the motion condition (mean = 18.94 transitions) compared to the no-motion condition (mean = 15.75 transitions), $F(1,5) = 7.955$, $p<.05$. However, there was no concomitant significant difference between the conformality conditions, and this difference attributed to motion was not reflected in any other measure.

Table 6. Summary of Analysis of Variance Results for Turn 2 (Downwind to Base)

Measure	**Conformality Condition ANOVA F-value F(3,15)**	**Conformality Condition ANOVA Probability value**	**Motion Condition ANOVA F-value F(1,5)**	**Motion Condition ANOVA Probability value**
Altitude Deviation Maximum	.556	.652 n.s.	5.752	.062 n.s.
Altitude Deviation Minimum	.701	.566 n.s.	.380	.565 n.s.
Altitude Mean	1.069	.392 n.s.	.045	.841 n.s.
Altitude Std. Dev.	1.296	.312 n.s.	.792	.414 n.s.
Roll – Maximum Left	2.585	.092 n.s.	.532	.499 n.s.
Roll – Maximum Right	.552	.654 n.s.	.178	.691 n.s.
Roll – Left Mean	2.148	.137 n.s.	.126	.737 n.s.
Roll Left Std. Dev.	1.136	.366 n.s.	.162	.704 n.s.
Other Aircraft Minimum Distance	.688	.573 n.s.	2.175	.200 n.s.
Left Looks (EOG)	.593	.629 n.s.	2.796	.155 n.s.
Heart Rate Mean	.701	.566 n.s.	.493	.514 n.s.
Heart Rate Std. Dev.	1.476	.261 n.s.	.531	.499 n.s.

** denotes $p < .01$, * denotes $p<.05$, n.s. denotes not significant ($p >.05$)

Table 7. Summary of Analysis of Variance Results for Turn 3 (Base to Final)

Measure	**Conformality Condition ANOVA F-value F(3,15)**	**Conformality Condition ANOVA Probability value**	**Motion Condition ANOVA F-value F(1,5)**	**Motion Condition ANOVA Probability value**
Altitude Deviation Maximum	.996	.422 n.s.	1.018	.359 n.s.
Altitude Deviation Minimum	1.089	.384 n.s.	2.041	.212 n.s.
Altitude Mean	.834	.496 n.s.	2.215	.197 n.s.
Altitude Std. Dev.	.485	.687 n.s.	.060	.817 n.s.
Roll – Maximum Left	.549	.656 n.s.	2.279	.192 n.s.
Roll – Maximum Right	.849	.489 n.s.	.493	.514 n.s.
Roll – Left Mean	.726	.552 n.s.	4.413	.090 n.s.
Roll Left Std. Dev.	.997	.421 n.s.	1.189	.325 n.s.
Other Aircraft Minimum Distance	.125	.944 n.s.	2.806	.155 n.s.
Left Looks (EOG)	1.612	.228 n.s.	**7.955**	**.037 ***
Heart Rate Mean	.630	.607 n.s.	.461	.527 n.s.
Heart Rate Std. Dev.	1.221	.336 n.s.	.055	.824 n.s.

** denotes p < .01, * denotes p<.05, n.s. denotes not significant (p >.05)

Approach and Landing

Analyses of flight technical error parameters were conducted at 1000 feet before runway threshold crossing, at 500 before threshold, and at threshold. A summary of ANOVA procedures conducted at these points is presented in Table 8. No significant differences were found for conformality or motion condition for altitude, sink rate (HDOT), or airspeed at any of the selected points. The landing touchdown simulated aircraft performance data ANOVA procedures are summarized in Table 9. The landing "touchdown" performance data showed no significant differences in touchdown sink rate. However, the touchdown point in the non-conformal conditions was found to be significantly further down the runway, $F(3,15) = 4.957$, $p<.02$, and at a significantly slower airspeed, $F(3,15) = 13.109$, $p<.001$. In addition, there was a significant motion/no motion effect for the touchdown airspeed, $F(1,5) = 15.409$, $p<.02$, with

slower airspeeds in the motion condition. This finding most likely represents a strategy chosen by the test subjects to touch down gently in the motion condition, which led to slower airspeed and, therefore, longer touchdown position, in order to avoid the pronounced bang/bump of the simulator at touchdown. A significant lateral position finding (Table 9) is probably not of practical significance as the mean difference was very small (approximately 5 feet).

Table 8. Summary of Analysis of Variance Results at selected points on final approach

Measure	**Conformality Condition ANOVA F-value F(3,15)**	**Conformality Condition ANOVA Probability value**	**Motion Condition ANOVA F-value F(1,5)**	**Motion Condition ANOVA Probability value**
Altitude 1000 ft before runway threshold	.343	.794 n.s.	.524	.502 n.s.
Vertical Rate (HDOT) 1000 ft before runway threshold	.111	.953 n.s.	2.049	.212 n.s.
Altitude 500 ft before runway threshold	.864	.481 n.s.	.164	.702 n.s.
Vertical Rate (HDOT) 500 ft before runway threshold	.789	.519 n.s.	1.164	.330 n.s.
Altitude at runway threshold	2.253	.124 n.s.	.006	.942 n.s.
Vertical Rate (HDOT) at runway threshold	1.298	.312 n.s.	.479	.520 n.s.

** denotes p < .01, * denotes p<.05, n.s. denotes not significant (p >.05)

Table 9. Summary of Analysis of Variance Results at Runway Touchdown

Measure	**Conformality Condition ANOVA F-value F(3,15)**	**Conformality Condition ANOVA Probability value**	**Motion Condition ANOVA F-value F(1,5)**	**Motion Condition ANOVA Probability value**
Longitudinal Runway Position	**4.957**	**.014 ***	4.107	.099 n.s.
Lateral Runway Position	**6.111**	**.006 ****	.098	.767 n.s.
Vertical Rate (HDOT)	.173	.913 n.s.	.576	.482 n.s.
Airspeed	**13.109**	**.001 ****	**15.409**	**.011 ***

** denotes p < .01, * denotes p<.05, n.s. denotes not significant (p >.05)

Hazard avoidance

The hazard avoidance scenarios (Scenarios 2, 3, and 5) were examined to determine if there were performance differences due to conformality condition, simulator motion, or their interaction. No significant differences in any of the parameters were noted for any of these scenarios. No significant differences were found in timing of avoidance maneuvers. Likewise, no significant differences in test subject heart rate or "looks" to the side window were found for these scenarios.

Mountain Scenario/Terrain Collision Avoidance

The mountain scenarios (Scenario 6) were all flown with motion on. No significant differences were found for the conformality condition in any of the flight technical or test subject objective behavior measures.

Subjective Data Analyses

Three subjective measures were taken during experimental trials: NASA TLX Workload Ratings, preference rankings of the (conformal and nonconformal) displays, and questionnaire ratings of display usability.

NASA TLX Workload Ratings

The NASA TLX scale (ref. 10) is given in Appendix D. This instrument is widely used to measure subjective evaluations of perceived workload and fatigue. There are six workload/fatigue categories evaluated by the subject: Mental, Physical, Temporal, Performance, Effort, and Frustration Level. Each category is associated with a ten-point scale, with zero considered the lowest value (e.g., little or no mental effort is required to perform the task) and 100 the highest value on that scale (e.g., maximum mental effort is required).

The TLX ratings from all subjects were combined and mean values were calculated for each of the six scales for motion/no motion conditions and across the four conformality display conditions for both Scenarios 1 and 4. These data are given in Appendix E and are summarized in Table 10 (for Scenario 1) and Table 11 (for Scenario 4).

Mean TLX ratings were compared by Analysis of Variance and showed no significant differences across main effect conditions of motion, scenario, or conformality and no significant interactions. This indicated that, as a group, the test subjects were not reporting significant differences in perceived workload or fatigue across the conditions under evaluation. It should also be noted that no high (>75) mean workload ratings were obtained in the test sessions.

Table 10. Mean Pilot Subjective Ratings of Perceived Workload for Scenario 1 Motion and No Motion Conditions (NASA TLX Scale)

MOTION

	Mental	Physical	Temporal	Perfor-mance	Effort	Frustration Level	Means
Conformal	40.8	38.3	40.0	30.8	37.5	17.5	34.15
4 Degrees	39.0	39.0	42.0	33.0	43.0	20.0	36.00
8 Degrees	41.7	38.3	32.5	25.0	38.3	20.8	32.77
8+Degrees	47.5	44.2	35.8	25.0	52.5	20.0	37.50

NO MOTION

	Mental	Physical	Temporal	Perfor-mance	Effort	Frustration Level	Means
Conformal	49.2	41.7	25	24.2	46.7	14.2	33.50
4 Degrees	42.5	40.8	30.8	30.8	46.7	19.2	35.13
8 Degrees	40.8	41.7	31.7	26.7	44.2	20	34.18
8+Degrees	41.7	33.3	29.2	19.2	38.3	14.2	29.32

Table 11. Mean Pilot Subjective Ratings of Perceived Workload for Scenario 4 Motion and No Motion Conditions (NASA TLX Scale)

MOTION

	Mental	Physical	Temporal	Performance	Effort	Frustration Level	Means
Conformal	42.5	42.5	41.3	33.8	50	25	39.18
4 Degrees	41	37	38	29	35	20	33.33
8 Degrees	30	37	32	34	28	24	30.83
8+Degrees	40	34	28	36	29	22	31.50

NO MOTION

	Mental	Physical	Temporal	Performance	Effort	Frustration Level	Means
Conformal	32.5	30	27.5	20	22.5	13.8	24.38
4 Degrees	41	38	32	26	39	26	33.67
8 Degrees	39	36	32	29	32	24	32.00
8+Degrees	39.2	35	31	28	34	22	31.53

Conformality/Nonconformality Display Preference Rankings

Subjects were also asked to rank order the four conformal/nonconformal displays for preference (with one the "most preferred" and four the "least preferred" display). These rankings are summarized in Table 12. All subjects except one preferred the conformal display. Verbal comments from the one pilot preferring the 8 degree non-conformal (22 degree total VFOV) display indicated that he may have been responding to a preference for a greater vertical field of view (relative to the 14 degree field used in all of the other conditions) rather than to conformality. As indicated by the means, the preference trend across all subjects was: conformal display most preferred, the 8+ degree display (with the wider field of view) next preferred, and the two nonconformal shortened field of view displays (4 and 8 degrees) least preferred.

Table 12. Pilot Preference Rankings of Conformal/nonconformal displays

Pilot	Conformal	4 Degree	8 Degree	8 Degree+
1	1	3	4	2
2	1	4	2	3
3	1	2	4	3
4	1	2	4	3
5	3	4	2	1
6	1	4	3	2
Mean Rankings	1.33	3.17	3.17	2.33

Conformality/Nonconformality Display Usability Ratings

A questionnaire was developed to assess the perceived "usability" of the conformal/ nonconformal displays. Subjects were asked to assess each display on a six-interval scale. The scale was structured such that the low anchor was "Much Less Effort Required" and the upper anchor was "Much More Effort Required," with a neutral anchor, "No More / No Less Effort Required." Subjects indicated each display's "usability" by selecting a rating on the scale with regard to a series of five questions:

(1) Usability of this configuration for maintaining level flight.

(2) Usability of this configuration for scanning for traffic.

(3) Usability of this configuration for landing approach.

(4) Usability of this configuration for landing flare

(5) Usability of this configuration for nose gear touchdown (de-rotation).

These data are provided in Appendix F and the means are summarized in Table 13 (by motion condition and display type for Scenarios 1 and 4). No trends or special results were found with these ratings. The results generally followed the trends indicated with the display preference ratings, i.e., generally the conformal and 8+ degree displays were preferred.

Table 13. Mean Pilot Ratings of Conformal & Nonconformal Displays
as a Function of Motion Condition and Scenario
(1 = "less effort"; 6 = "more effort")

Condition	Conformal	4 Degree	8 Degree	8 Degree+
Scenario 1				
Motion	4.3	4.0	4.5	4.1
No Motion	3.3	3.3	3.3	2.9
Scenario 4				
Motion	2.9	3.4	3.5	3.3
No Motion	3.1	3.2	3.6	3.4

Pilot Comments

While completing the questionnaire, subjects were permitted to annotate their ratings with comments. The majority of comments related to the design or usability of the XVS symbology, display clutter, "blind spots," and difficulties with the VMS structure occluding parts of the visual field. The pilot comment data were not statistically analyzed, but were collected and organized for readability. All pilot comments made on the questionnaires are provided for reference in Appendix G.

General Conclusions and Recommendations

This experiment is one of a series of experiments exploring the "design space" restrictions for placement of an XVS display. In this study, the primary experimental issue examined was conformality of the forward display vertical position with respect to the side window in simulated flight conditions. In particular, this study quantified the effects of visual conformality on pilot flight path control and hazard avoidance performance. For this study, conformality related to the positioning and relationship of the horizon line and associated symbology presented on the forward display and the horizon and associated ground, horizon, and sky textures presented in the side window display. The side window, though computer generated, represented a real window and a view of the real world. For this experiment the forward display symbology was presented as conformal or shifted up by 4 or 8 degrees visual angle. This shift was incorporated to permit the desired amount of below-horizon look-down angle on the forward displays on approach for the high angle of attack HSCT.

With regard to the three primary hypotheses under test in the present study, the results were as follows: (1) There was no evidence to support the first hypothesis that flight control performance and airborne hazard detection would be degraded in the nonconformal conditions. No operationally significant display conformality effects were noted in terms of simulated aircraft performance measures during the approach phase, turns or during hazard avoidance scenarios. An effect on runway "touchdown" point and airspeed was found and an explanation

was noted for this finding. (2) The second hypothesis was supported in that no significant differences were found between motion and no-motion throughout the tests except for touchdown "footprint" location and airspeed which may have been a function of performance of the VMS simulator (discussed below). (3) While pilots typically express a preference for conformal displays, the general feeling was that the changes in VFOV could be adapted to through training. The overall restriction in VFOV angle used in this experiment may have been a larger factor in acceptability and use than the shift in VFOV.

The findings of this and related conformality experiments may impact the location and positioning of displays and sensors driving the displays in the HSCT. The results of this study indicate that VFOV displacements of 4 or 8 degrees in the forward display may be accomplished with minimal consequences on performance. No cases of simulator sickness or other physical signs of motion discomfort or vestibular effects were reported by the test subjects for any of the display conditions.

Touchdown and Flare

No significant differences were observed in positional or rate measures at 1000 feet before runway threshold, or 500 feet before threshold, or at runway threshold. The landing "touchdown" (defined by main gear touchdown) performance data showed no significant differences in touchdown sink rate. However, the touchdown point in the non-conformal conditions was found to be significantly further down the runway and the touchdown was accomplished at a significantly lower airspeed. These findings may reflect uncertainty about flaring the aircraft when there is a large amount of forward scene and side window mismatch. This finding most likely represents a strategy chosen by the test subjects to touch down gently in the motion condition, which led to longer touchdown position and slower airspeed in order to avoid the pronounced bang/bump of the simulator at touchdown. Pilot comments indicated that non-conformal VFOV displays for flaring the aircraft were different but could be adapted to through training.

Turns when following a lead aircraft

In the scenarios that required following traffic on downwind, base, and final, specific attention was paid to the data from the downwind to base and base to final turns, as these were times when the lead aircraft would transition from the forward display to the side window and back to the forward display. No significant differences were observed in any of the aircraft position or position deviation data across the conformality conditions. Likewise, no significance by conformality condition was noted in the EOG-based measure of the number of looks from the forward display to the side window.

It should be noted that all bank angles were relatively shallow, perhaps a function of the limited vertical field of view in which it was easy to decrease the horizon in view when it was occluded by both the top and bottom of the display. In addition, the horizon could easily move up and out of the left side window in a left turn, meaning that only ground could be seen because of the limited field of view of the side window display.

Hazard avoidance

Examination of the set of data from the hazard avoidance scenarios showed that the conformality factor had no effect on performance in these scenarios. Specific performance indicators examined included: time of beginning avoidance maneuver, pitch and roll angles (both sustained and maximum angles reached), aircraft position and airspeed, heading and altitude errors, distance from target/hazard, and frequency of left window looks (an EOG-based measure). Narrative remarks during the mountain scenarios indicated that non-conformality was most noticeable in those scenarios. This may be due to the fact that a fixed or level horizon was no longer present in the side window (or front scene, other than XVS symbology). Remarks also noted the increased value of the XVS horizon line and flight path vector when an irregular horizon, such as from mountain peaks or ridge lines, is present.

Subjective Ranking

Subjective rankings of the display conditions revealed that five of the six pilots preferred the conformal display. Verbal comments from the one pilot preferring the 8-degree non-conformal (22 degree total VFOV) display indicated that he may have been responding to a preference for a greater VFOV (relative to the 14 degree field used in all of the other conditions) than to the conformality issue. The VFOV was masked in three of the four conditions in order to maintain the same amount of "lookdown" angle for each of the conformality conditions.

Lessons Learned

It is possible that the effects of non-conformality may have been understated in the present simulator experiment due to the wide pillar between the front display and the side window (approximately 12 to 15 degrees visual angle) in the VMS facility. In addition, the effect on landing flare of the limited VFOV used in this study is unknown and may have led to the longer touchdown distances that were observed.

Another limitation concerns the hazards employed in the present study. Replications of experimental runs meant that test subjects saw similar hazards more than once. Obviously, the hazard could only be a "surprise" once, so it would be recommended that future studies incorporate hazards that are unpredictable in timing and/or location. Additional recommendations include: (1) the future use of "breakout" scenarios to assess display use in low visibility conditions; (2) increased subject pilot workload through "full mission" approaches, including events and activities such as ATC calls, crew interactions, last minute runway changes, weather at minimums, crosswinds, cockpit interruptions; and (3) increased sample size to reduce overall between-subject variability.

Summary

The incongruities in visual cues associated with nonconformality in vertical display location had minimal performance consequences on a simulated approach and landing task based on testing of six pilots in the NASA Langley VMS. Performance effects observed were noted above. No cases of simulator sickness or other physical signs of motion discomfort or vestibular effects were reported for any of the display conditions. When asked to rank the display

conditions, five out of six pilot subjects preferred the conformal display condition.

Factors to consider in interpreting these findings include: (1) the limited VFOV of the XVS display evaluated here due to hardware and experimental constraints, (2) the wide pillar separating the forward display and the side window (about 12 to 15 degrees), (3) the effect of limited VFOV on bank angle, (4) all hazards used in the experiment could be described as "slow onset," meaning that sudden, immediate, and large control inputs were not required for hazard avoidance, and (5) all hazard scenarios incorporated good visibility (Visual Meteorological Conditions, or VMC). It would be valuable to evaluate conformality effects on hazard detection and avoidance in break-out conditions or other situations where a rapid "mental reconstruction" of the visual scene or situation was required.

While the High Speed Research (HSR) program was cancelled prior to industry construction of a prototype aircraft using the display concepts under test here, these results have implications beyond the HSR program. These findings are important for activities of the Synthetic Vision Systems element of the Aviation Safety Program which faces issues of non-conformality in terms of Head-Down Display field-of-view and display scene "minification". Additionally, these findings have implications for display design in general and as a stepping stone for future efforts in forward displays for High Speed Aircraft on which a no-droop nose concept is chosen.

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Appendix A
Summarized Pilot Subjects Information

I. Pilot Experience

Subject	Years Flying Commercial	Years Flying Military	Total Hours Flying	Total Hours As Pilot-in-Command	Glass Cockpit Experience (years)
1. F/O	6	10	5348	2600	1-5
2. Capt	18	--	17,000+	15,000+	0
3. F/O	8	21	10,000	4,000	6
4. F/O	4.5	20	5,700	3,200	1-5
5. F/O	7	--	3,700	3,200	0
6. F/O	15	--	9,500	6,500	1-5
Means	9.75 Years	17 Years	8,541 Hours	5,300 Hours	0 years N=2 1-5 years N=3 6+years N=1

II. Aircraft Types Flown by Pilot Subjects

- B727, B737-200/300/400, B747, B757, B767
- DC-9, MD-80
- T-37, T-38, T-39, T-44
- F-100, F15
- E-1, E2C
- DHC-7, DHC-8
- SD-330
- B-99
- Gulfstream IV
- Grumman GA-7

Appendix B
Objective & Subjective Dependent Measures

OBJECTIVE MEASURES of AIRCRAFT STATE

<u>1 Hz data rate from start to end of run</u>

Pilot, Run, and Scenario number
Display conformality condition (0º, 4º, 8º, 8º+)
Elapsed time
Aircraft position in X, Y, and Z
Aircraft attitude:
- psi (heading)
- phi (roll)
- theta (pitch)

Aircraft indicated airspeed
Target aircraft position (Xt, Yt, Zt) (for all targets)
Distance to target aircraft (for all targets)

<u>20 Hz data rate from five nm to touchdown</u>

Pilot, Run, and Scenario number
Display conformality condition (0º, 4º, 8º, 8º+)
Elapsed time
Lateral path error (feet)
Vertical path error (feet)
Pitch, Roll, and Sink rates
Side-arm controller pitch input angle
Side-arm controller roll input angle
Rudder peddal position
Throttle position
Engine power (%)

<u>Single event data upon touchdown</u>

Pilot, Run, and Scenario number
Display conformality condition (0º, 4º, 8º, 8º+)
At first gear touchdown:
- Aircraft position (X, Y)
- Elapsed time
- Sink rate
- Lateral velocity
- Indicated airspeed

At nosewheel touchdown:

- Aircraft position (X, Y)
- Elapsed time
- Lateral velocity
- Pitch rate

OBJECTIVE MEASURES of PILOT SUBJECT STATE

Heart rate (measured via earclip plethysmograph)
EOG (electro-oculogram to detect “left looks”)

SUBJECTIVE MEASURES

NASA TLX Workload Rating Scale
Usability Questionnaire concerning display conformality
Pilot comments

Appendix C
Example Pilot Subject Running Order

DAY ONE

Training (All No Motion Trials)		Experiment 2 No Motion Trials		Experiment 2 Motion Trials	
Scenario	**Fwd Angle**	**Scenario**	**Fwd Angle**	**Scenario**	**Fwd Angle**
				T1	4
T1	0	4	8	4	4
T1	0	4	8	5	4
T2	0	4	8	4	4
T2	0	4	4	4	4
		4	4	5	4
T1	0	4	4	5	4
T1	0	4	0	5	8+
T2	0	4	0	4	8+
T2	0	4	0	5	8+
T1	4	4	8+	4	8+
T1	4	4	8+	4	8+
T2	4	4	8+	5	8
T2	4			4	8
T1	8			4	8
T1	8			5	8
T2	8			4	8
T2	8			4	0
T1	8+			5	0
T1	8+			4	0
T2	8+			4	0
T2	8+			5	0
Total	20	Total	12	Total	21

Terrain Collision Avoidance Trials
(All with Motion)

Scenario	Fwd Angle
6	8+
6	4
6	0
6	8
Total	4

DAY TWO

Experiment 1

Motion Trials		No Motion Trials	
Scenario	**Fwd Angle**	**Scenario**	**Fwd Angle**
T1	8+		
T1	8+		
1	8+	1	0
2	8+	1	0
3	8+	1	0
1	8+	1	8
3	8+	1	8
1	8+	1	8
2	8+	1	8+
3	8+	1	8+
2	8+	1	8+
1	0	1	4
3	0	1	4
2	0	1	4
1	0		
2	0		
3	0		
1	0		
1	4		
2	4		
3	4		
1	4		
1	4		
2	4		
3	4		
1	8		
2	8		
1	8		
3	8		
2	8		
1	8		
3	8		
Total	33	Total	12

Appendix D
NASA TLX Workload Rating Scale

Title & Description

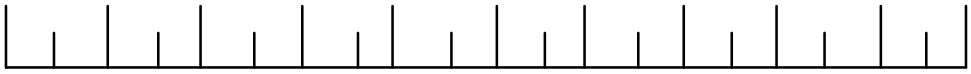
MENTAL DEMAND:
How much mental and perceptual activity was required (e.g., thinking, deciding, calculating, remembering, looking, searching, etc.)? Was the task easy or demanding, simple or complex, exacting or forgiving?

Mental Demand

Low High

PHYSICAL DEMAND:
How much physical activity was required (e.g., pushing, pulling, turning, controlling, activating, etc.)? Was the task easy or demanding, slow or brisk, slack or strenuous, restful or laborious?

Physical Demand



Low High

TEMPORAL DEMAND:
How much time pressure did you feel due to the rate or pace at which the tasks or task elements occurred? Was the pace slow and leisurely or rapid and frantic?

Temporal Demand

Low High

PERFORMANCE:
How successful do you think you were in accomplishing the goals of the task set by the experimenter (or yourself)? How satisfied were you with your performance in accomplishing these goals?

Performance

Good Poor

EFFORT:
How hard did you have to work (mentally and physically) to accomplish your level of performance?

Effort

Low High

FRUSTRATION LEVEL:
How insecure, discouraged, irritated, stressed and annoyed versus secure, gratified, content, relaxed and complacent did you feel during the task?

Frustration

Low High

Appendix E

Summary of NASA TLX Ratings for Scenario 1 and Scenario 4 Motion and No Motion Conditions across Conformality Displays

Scenario 1
No Motion

	Mental	Physical	Temporal	Performance	Effort	Frustration Lvl
Conformal	60	60	50	20	50	5
	40	35	25	50	40	40
	5	5	5	10	10	0
	45	45	35	50	65	35
	85	75	25	5	95	5
	60	30	10	10	20	0
Means	**49.2**	**41.7**	**25**	**24.2**	**46.7**	**14.2**
4 Degrees	60	65	65	15	60	10
	55	45	45	60	65	65
	0	0	0	0	0	0
	45	45	45	50	65	35
	75	75	25	5	85	5
	20	15	5	10	5	0
Means	**42.5**	**40.8**	**30.8**	**23.3**	**46.7**	**19.2**
8 Degrees	60	65	55	20	60	10
	65	60	50	45	70	50
	0	0	0	0	0	0
	45	45	45	50	65	35
	55	65	25	35	65	25
	20	15	15	10	5	0
Means	**40.8**	**41.7**	**31.7**	**26.7**	**44.2**	**20**
8 Degrees+	65	60	55	15	55	5
	45	40	30	30	30	25
	0	0	0	0	0	0
	55	55	45	45	65	35
	75	35	35	15	75	20
	10	10	10	10	5	0
Means	**41.7**	**33.3**	**29.2**	**19.2**	**38.3**	**14.2**

Scenario 1
Motion

	Mental	Physical	Temporal	Performance	Effort	Frustration Lvl
Conformal	60	65	55	15	60	10
	45	45	60	60	65	40
	20	10	20	15	10	5
	35	35	35	50	55	25
	75	65	55	35	30	25
	10	10	15	10	5	0
Means	**40.8**	**38.3**	**40**	**30.8**	**37.5**	**17.5**
4 Degrees	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	45	45	45	50	40	35
	10	10	10	10	10	0
	45	45	45	50	65	35
	80	80	70	35	80	20
	15	15	40	20	20	10
Means	**39**	**39**	**42**	**33**	**43**	**20**
8 Degrees	70	75	50	10	75	10
	55	35	35	50	30	55
	10	10	10	10	10	0
	45	45	45	50	70	35
	60	55	50	20	45	25
	10	10	5	10	0	0
Means	**41.7**	**38.3**	**32.5**	**25**	**38.3**	**20.8**
8 Degrees +	75	70	60	20	65	10
	65	65	50	40	70	50
	20	10	10	20	20	10
	45	45	45	50	75	35
	70	65	45	10	75	15
	10	10	5	10	10	0
Means	**47.5**	**44.2**	**35.8**	**25**	**52.5**	**20**

Scenario 4
No Motion

	Mental	Physical	Temporal	Performance	Effort	Frustration Lvl
Conformal	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	(No Subj 2)	(No Subj 2)	(No Subj 2)	(No Subj 2)	(No Subj 2)	(No Subj 2)
	10	10	10	10	10	0
	50	50	45	50	55	45
	60	50	45	10	25	10
	10	10	10	10	0	0
Means	**32.5**	**30**	**27.5**	**20**	**22.5**	**13.8**
4 Degrees	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	35	35	35	35	35	35
	20	20	20	20	20	10
	50	50	50	50	70	65
	80	65	45	15	70	20
	20	20	10	10	0	0
Means	**41**	**38**	**32**	**26**	**39**	**26**
8 Degrees	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	45	45	45	55	50	40
	20	20	20	20	20	10
	50	50	50	50	65	60
	60	45	35	10	15	10
	20	20	10	10	10	0
Means	**39**	**36**	**32**	**29**	**32**	**24**
8 Degrees +	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	56	45	45	50	45	55
	10	10	10	10	10	0
	50	50	50	50	60	40
	60	50	40	20	55	15
	20	20	10	10	0	0
Means	**39.2**	**35**	**31**	**28**	**34**	**22**

Scenario 4
Motion

	Mental	Physical	Temporal	Performance	Effort	Frustration Lvl
Conformal	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	60	60	60	40	65	35
	5	5	10	10	10	0
	25	25	25	50	50	25
	80	80	70	35	75	40
	(No Subj 6)	(No Subj 6)	(No Subj 6)	(No Subj 6)	(No Subj 6)	(No Subj 6)
Means	**42.5**	**42.5**	**41.3**	**33.8**	**50**	**25**
4 Degrees	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	35	25	25	25	25	25
	10	10	20	10	10	0
	50	50	50	50	60	40
	80	80	75	40	70	35
	30	20	20	20	10	0
Means	**41**	**37**	**38**	**29**	**35**	**20**
8 Degrees	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	20	50	40	60	45	70
	0	5	10	10	10	0
	25	25	25	50	40	35
	75	75	65	20	25	15
	30	30	20	30	20	0
Means	**30**	**37**	**32**	**34**	**28**	**24**
8 Degrees +	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)	(No Subj 1)
	45	35	35	35	35	30
	5	5	5	10	10	0
	45	45	50	50	55	45
	70	55	45	15	25	25
	35	30	5	70	20	10
Means	**40**	**34**	**28**	**36**	**29**	**22**

Appendix F
Summary of Display Usability Questionnaire Ratings
(1 = "Much Less Effort Required" and 6 = "Much More Effort Required")

Q1. Usability of this configuration for maintaining level flight.
Q2. Usability of this configuration for scanning for traffic.
Q3. Usability of this configuration for landing approach.
Q4. Usability of this configuration for landing flare
Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Scenario 1
No Motion

	Question	Conf	4 deg	8 deg	8+ deg
Q1.	Usability of this configuration for maintaining level flight.	3.1	3	3.1	2.8
Q2.	Usability of this configuration for scanning for traffic.	3.1	3.1	2.8	2.5
Q3.	Usability of this configuration for landing approach.	3.5	3.3	3.3	2.8
Q4.	Usability of this configuration for landing flare	3.5	3.7	3.5	3.3
Q5.	Usability of this configuration for nose gear touchdown (de-rotation).	3.4	3.4	3.7	3.3
	Mean Rating	3.3	3.3	3.3	2.9

Scenario 1
Motion

	Question	Conf	4 deg	8 deg	8+ deg
Q1.	Usability of this configuration for maintaining level flight.	4.3	4.1	4.1	4.3
Q2.	Usability of this configuration for scanning for traffic.	4.3	4	4.6	4
Q3.	Usability of this configuration for landing approach.	4.5	4	4.5	4
Q4.	Usability of this configuration for landing flare	4.2	3.7	4.6	4.2
Q5.	Usability of this configuration for nose gear touchdown (de-rotation).	4.1	3.7	4.5	4.3
	Mean Rating	4.3	4	4.5	4.1

Scenario 4
No Motion

	Question	Conf	4 deg	8 deg	8+ deg
Q1.	Usability of this configuration for maintaining level flight.	2.8	2.9	3	3.2
Q2.	Usability of this configuration for scanning for traffic.	3.2	3.5	3.2	3.2
Q3.	Usability of this configuration for landing approach.	3.2	3.2	3.6	3.4
Q4.	Usability of this configuration for landing flare	3.2	3.1	4.2	3.6
Q5.	Usability of this configuration for nose gear touchdown (de-rotation).	3.4	3.4	3.7	3.3
	Mean Rating	3.1	3.2	3.6	3.4

Scenario 4
Motion

	Question	Conf	4 deg	8 deg	8+ deg
Q1.	Usability of this configuration for maintaining level flight.	2.8	3.2	3.3	3.1
Q2.	Usability of this configuration for scanning for traffic.	3.3	3.4	3.4	3.3
Q3.	Usability of this configuration for landing approach.	2.8	3.3	3.3	3.1
Q4.	Usability of this configuration for landing flare	2.8	3.4	3.8	3.6
Q5.	Usability of this configuration for nose gear touchdown (de-rotation).	3	3.5	3.7	3.6
	Mean Ratings	2.9	3.4	3.5	3.3

Appendix G
Pilot Comments
(Organized by Scenario, Motion/No Motion, and Question)

The following are transcribed responses of handwritten comments in the blank space provided following each of the rating scale questions noted below.

<u>Scenarios 1, 2, and 3 No Motion:</u>

- ***Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Q2. Usability of this configuration for scanning for traffic.

Felt better about aircraft ahead and below me without mask

Except for blind spots

Q3. Usability of this configuration for landing approach.

Glidepath adjustment was easy and more normal looking

Q4. Usability of this configuration for landing flare

This configuration was very easy (in landing flare).

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Found myself varying the flight path to keep traffic in sight.

General: When would you expect problems with this display configuration:

This configuration looked more normal as I perceived it.

No problems.

"Blind area" between front and side view is distracting. [Resulting from the simulator.]

- ***4 degree Non-conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

HUD easy to use.

Q2. Usability of this configuration for scanning for traffic.

Except for blind spots.

Less effort in this case for following the traffic because of the wide view of the horizon.

Q3. Usability of this configuration for landing approach.

Had little problem ?? on last 200 feet. Adjusted glidepath and everything okay.

Better view of ground references.

Q4. Usability of this configuration for landing flare

Last configuration was a little easier to use.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Appeared to carry a little less nose high attitude at touchdown.

General: When would you expect problems with this display configuration:

None except previously noted airspeed display partially cut out by upper mask.

Blind spots for scanning bothered me a little. Adjustment for glide path took two approaches to cross threshold at 50 feet.

HUD display too big for instrument flying. Needs to have pitch references at least every 2.5 degrees.

With top and bottom masking it would be more difficult to see traffic, both during high angles of attack and maneuvering in dense terminal areas with traffic above.

Maybe looking for traffic above flight path.

- ***8 degree Non-conformal Condition***

  Q1. Usability of this configuration for maintaining level flight.
  Harder to maintain level flight.
  Q2. Usability of this configuration for scanning for traffic.
  Same except for blindspots.
  With masking on the bottom, tends to have too much data cluttered in vertical field of view. The display seems to have no effect on this.
  Q3. Usability of this configuration for landing approach.
  Required more effort to establish glide path.
  Difficult to see target from 6 o'clock.
  Better in this case for traffic below flight path.
  Q4. Usability of this configuration for landing flare
  Masked top cuts off some symbology and degrades horizon cues.
  I might have been flaring too early on this one.
  Q5. Usability of this configuration for nose gear touchdown (de-rotation).
  Too much nose up attitude which was difficult to correct for.
  General: When would you expect problems with this display configuration:
  During climbout with a high angle of attack and traffic crossing below.
  May not see traffic above flight path.

- ***8 degree+ Non-conformal Condition***

  Q1. Usability of this configuration for maintaining level flight.
  Easy to maintain.
  Q2. Usability of this configuration for scanning for traffic.
  Except for blind spots.
  Even with the non-conformal view the traffic is quite predictable as to where it will be when it moves from front screen to side window.
  Best display in this case (traffic below flight path).
  Q3. Usability of this configuration for landing approach.
  Glideslope and threshold were easy to judge.
  Best in this case (ground reference used to fly approach).
  Q4. Usability of this configuration for landing flare
  Much better than masked displays.
  Easy to judge flare point.
  Full view no mask tends to fly a 3 degree glideslope rather than a flat 2 1/2 degree approach.
  Q5. Usability of this configuration for nose gear touchdown (de-rotation).
  OK.
  General: When would you expect problems with this display configuration:
  Blind spots -- panoramic view would make everything easier.
  No problems expected.
  May be distracting when HUD not used. May be hard to see traffic above flight path.

<u>Scenarios 1, 2, and 3 Motion:</u>

- ***Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.
Fairly easy to stay level.
Q2. Usability of this configuration for scanning for traffic.
Surprised to pick traffic out side window so easily.
Many blind spots.
You cannot see enough above you, especially during turns in excess of 20 degees bank.
Q3. Usability of this configuration for landing approach.
Felt comfortable, easy to gauge glide path.
In fact, I feel that the masked top creates a higher than actual altitude, leading to a low flat approach.
Q4. Usability of this configuration for landing flare
Comfortable with flare in this configuration.
Q5. Usability of this configuration for nose gear touchdown (de-rotation).
Average.

General: When would you expect problems with this display configuration:
Blind areas.
During extensive maneuvering in a highly congested terminal area, not enough vertical picture.

- ***4 degrees Non-Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.
Q2. Usability of this configuration for scanning for traffic.
Same in all configurations.
Traffic hard to see on final approach.
Vertical field of view still slightly limited.
Limited vertical field of vision.
Q3. Usability of this configuration for landing approach.
Easier than last configuration (Subject 2).
The limited view tends to make me fly a flat approach.
Q4. Usability of this configuration for landing flare
Easier to judge flare point and crossing threshold at 50 feet.
Q5. Usability of this configuration for nose gear touchdown (de-rotation).
Same as before.
General: When would you expect problems with this display configuration:
Blind spots. Hard to see traffic on final.

- ***8 degrees Non-Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.
Less effort to maintain than last configuration (Subj 1).
Q2. Usability of this configuration for scanning for traffic.
Same as others.
Did not initially see second aircraft -- observed him on following runs.

With the HUD not decluttered, the traffic sometimes becomes obscured by the alphanumeric symbols on left hand display.
Disparity between side & front view requires you to "shift gears" mentally to predict where traffic will be on other screen.

Q3. Usability of this configuration for landing approach.
Easier to judge glide path.
Somewhat restricted downward view.

Q4. Usability of this configuration for landing flare
Less effort and concentration than last configuration (Subj 1).
Restricted downward view.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).
Same as before.

General: When would you expect problems with this display configuration:
No problem anticipated in this scenario.
It's a little more difficult looking from one point in the forward window to a different point on the side window to follow traffic during visual approaches.
Restricted view for traffic, conflict between side and forward view.

- ***8 degree+ Non-conformal Condition***

Q1. Usability of this configuration for maintaining level flight.
I felt like I had to work harder to maintain level flight.

Q2. Usability of this configuration for scanning for traffic.
Same as other configuration.
Alphanumeric symbols still obscure traffic on left hand side of display.
Best field of vision.

Q3. Usability of this configuration for landing approach.
More effort expended trying to maintain a proper glide path.

Q4. Usability of this configuration for landing flare
More effort to judge proper flare point; okay on crossing fence at 50 feet.
Configuration seems to have no effect on this as long as HUD is used.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).
Same as other configuration.
You see a wide portion of runway environment. Because of this, de-rotation rate could be slower than normal.

General: When would you expect problems with this display configuration:
Blind spot between side and forward visual displays made it difficult to keep traffic in sight.
The disparity between the side view and forward view seems to be only a factor if HUD not used.

<u>Scenarios 4 and 5 No Motion:</u>

- ***Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Q2. Usability of this configuration for scanning for traffic.

Same as others.

Q3. Usability of this configuration for landing approach.

HUD roll command bars made HUD busy and had to concentrate on scene more.
Most "normal" and easiest configuration.

Q4. Usability of this configuration for landing flare

Thought I was crossing threshold high and fast.
Much less effort required because this is what pilots have been used to seeing for years.
That doesn't mean that non-conformality is harder during flare. It is just different.
Side window perception most useful.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Same as last configuration.
Use forward reference only.

General: When would you expect problems with this display configuration:

Crosswind landings due to HUD symbology obscuring runway.
No problems expected.
Most "natural" configuration.

- ***4 degree Non-Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Display seems to have no effect on this parameter.

Q2. Usability of this configuration for scanning for traffic.

You have to project where aircraft/traffic may be and look in that part of the screen.

Q3. Usability of this configuration for landing approach.

Felt good and looked good on glideslope.

Q4. Usability of this configuration for landing flare

Masking did not add or detract from display.
Tendency to be nose high, but with a little attention, that can be avoided.
Not an unusual amount of depth perception lost as one would expect for non-conformality.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Masking did not add or detract from display.
Okay if avoiding nose high attitude.

General: When would you expect problems with this display configuration:

No problems anticipated.
Looking for traffic in a reduced visibility situation and trying to project where that aircraft would be while keeping your instrument scan during the approach.

- ***8 degree Non-conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Q2. Usability of this configuration for scanning for traffic.

Same as other configurations.

Q3. Usability of this configuration for landing approach.

Looked and felt good on glideslope/threshold crossing.

Q4. Usability of this configuration for landing flare

Same comments as 4 degrees on horizon. Masking the bottom made picture seem more realistic in depth since there wasn't as much ground in view.

Still a tendency for nose high.
Side window less useful.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Same as 4 degree with horizon very limited.
Still a tendency for nose high. Have to concentrate on attitude to avoid slamming nose down.
Aircraft symbol not visible to assist in directional control.

General: When would you expect problems with this display configuration:

No problems expected.
Once again, conflict between side window and forward takes some getting used to; seem to adapt fairly quickly.

- ***8 degree+ Non-conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Q2. Usability of this configuration for scanning for traffic.

Same as other configurations.
Your eyes have to look at a greater angle on the windscreen due to the larger non-conformality, but it's still nothing I would consider unsafe.
Lower field of vision helps to scan for traffic while descending (lower traffic)

Q3. Usability of this configuration for landing approach.

Approach threshold crossings a little high and touchdown beyond 1000 foot marker; glideslope seemed okay.

Q4. Usability of this configuration for landing flare

Not as much horizon available but otherwise no extra effort.
Flare seemed a little easier than last configuration. (Subject 2)
The projection of more ground could give the appearance of the aircraft being high. Therefore, starting flare late.
Lower field of vision helps landing flare.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Not as much horizon available but otherwise no extra effort.
About the same as other configurations.
Directional control slightly more difficult.

General: When would you expect problems with this display configuration:

Rollout directional cues less with less horizon in view.
No problems expected.
During a strong crosswind, in which case the aircraft is crabbing into the wind, you will see more of the picture of the true horizon out of the side window. This could create a possible visual illusion.

<u>Scenarios 4 and 5 Motion:</u>

- ***Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

It was easier to level after MAP.
No problem.

Q2. Usability of this configuration for scanning for traffic.

In a reduced vertical field of view, traffic is more difficult to see.

Q3. Usability of this configuration for landing approach.

The conformal view was nicer and felt more "normal," even though non-conformal view was distracting me.

Approach angles were easier to judge.

Q4. Usability of this configuration for landing flare

Much better picture for flare and sink rate perception. Good horizon picture, even with top mask.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Much better picture for flare and sink rate perception. Good horizon picture, even with top mask.

Directional control easier.

General: When would you expect problems with this display configuration:

With top mask, part of the ground speed readout on HUD is cut off. It's not a big enough cutout to prevent reading the numbers, but could be confusing with some digits.

No problem expected.

Approach runway for landing (in close).

I find the 0 degree display more used to what I normally see and I am more comfortable with it. The 4 & 8 deg offsets create a conflict of approach angle/altitude between what is perceived out the front vs. side window, which is distracting but fairly easy to "get used to."

• **4 degree Non-Conformal Condition**

Q1. Usability of this configuration for maintaining level flight.

Roll command on HUD gets busy with other indications.

Q2. Usability of this configuration for scanning for traffic.

Q3. Usability of this configuration for landing approach.

I might be flying sim better, but felt approaches were better with regard to glideslope and airspeed.

Q4. Usability of this configuration for landing flare

Masking at 4 degrees did not affect view.

Seemed to have better cues.

Side window reference more useful.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

Much better horizon reference and depth perception.

Slight tendency to get nose high.

Minor difficulty with directional control on rollout.

General: When would you expect problems with this display configuration:

None.

None expected.

• ***8 degree Non-Conformal Condition***

Q1. Usability of this configuration for maintaining level flight.

Q2. Usability of this configuration for scanning for traffic.

Bottom mask could obscure search for traffic ahead/below you to same runway.

Difficult to see traffic at 2 o'clock.

In some instances, it requires longer to re-acquire traffic due to the larger non-conformality.

Q3. Usability of this configuration for landing approach.

I would prefer to have a reduced clutter HUD while keeping the heading function. Otherwise, you have to reach cross cockpit and push the HUD clutter button 3 times to get heading information in case of go-around.

Q4. Usability of this configuration for landing flare

I preferred having a bottom mask to a top mask, since I shift my scan to the end of the runway/horizon in the flare.

Like the "full view" of the runway better.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

You lose the end of the runway when nosewheel touches down; maybe there could be a shift function that, once nosegear compresses, display shifts further forward rather than down at ground.

General: When would you expect problems with this display configuration:

Searching for traffic ahead/below as previously noted with bottom mask, during landing and rollout without proper power management.

No problems.

Scanning for traffic below the nose of the aircraft.

• 8 degree+ Non-conformal Condition

Q1. Usability of this configuration for maintaining level flight.

Don't know whether this is a function of me flying the sim better or the HUD being less cluttered (2.5 rating).

Q2. Usability of this configuration for scanning for traffic.

Particularly for traffic beside and above, not in front of, you

Q3. Usability of this configuration for landing approach.

Approach seemed easier for crossing the threshold at 50 feet.

Q4. Usability of this configuration for landing flare

With HUD symbology on full (not decluttered), horizon was obscured by symbols, which affected sink rate perception and depth perception by a small margin.

Seem to be a little nose high, but airspeed control was better.

Side window less useful.

Q5. Usability of this configuration for nose gear touchdown (de-rotation).

With HUD symbology on full (not decluttered), horizon was obscured by symbols, which affected sink rate perception and depth perception by a small margin.

Tendency to get nose high, but with a little attention, that can be avoided.

Appear to better see end of runway during rollout.

General: When would you expect problems with this display configuration:

Hazy day, horizon obliterated, which might affect visual cues.

No problem noted.

This forward view, one would be able to better see smaller aircraft and other smaller obstructions.

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13. ABSTRACT *(Maximum 200 words)*
Researchers within the eXternal Visibility System (XVS) element of the High-Speed Research (HSR) program developed and evaluated display concepts that will provide the flight crew of the proposed High-Speed Civil Transport (HSCT) with integrated imagery and symbology to permit path control and hazard avoidance functions while maintaining required situation awareness. The challenge of the XVS program is to develop concepts that would permit a no-nose-droop configuration of an HSCT and expanded low visibility HSCT operational capabilities. This study was one of a series of experiments exploring the “design space” restrictions for physical placement of an XVS display. The primary experimental issue here was “conformality” of the forward display vertical position with respect to the side window in simulated flight. “Conformality” refers to the case such that the horizon and objects appear in the same relative positions when viewed through the forward windows or display and the side windows. This study quantified the effects of visual conformality on pilot flight path control and hazard avoidance performance. Here, conformality related to the positioning and relationship of the artificial horizon line and associated symbology presented on the forward display and the horizon and associated ground, horizon, and sky textures as they would appear in the real view through a window presented in the side window display. No significant performance consequences were found for the non-conformal conditions.

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