Human Factors Issues In Synthetic Vision Displays: Government, Academic, Military, and Industry Perspectives

Lawrence J. Prinzel III, Ph.D.
NASA Langley Research Center
Hampton, VA
Organizer and Chair

J. Raymond Comstock, Jr., Ph.D.
NASA Langley Research Center
Hampton, VA
Co-Chair

Panelists

Tim Etherington
Rockwell Collins
Cedar Rapids, IA

Guy A. French, Ph.D.
Air Force Research Laboratory
Wright-Patterson AFB, OH

Michael P. Snow, Ph.D.
The Boeing Company
Seattle, WA

Mica R. Endsley, Ph.D.
SA Technologies, Inc.
Marietta, GA

Christopher D. Wickens, Ph.D.
University of Illinois
Urbana-Champaign, IL

Kevin M. Corker, Ph.D.
San Jose State University
San Jose, CA

Background

Aviation has been witness to rapid advancement in technologies that have significantly improved aviation safety. The development of attitude indicators, flight management systems, radio navigation aids, and instrument landing systems (ILS) have extended aircraft operations into weather conditions with reduced forward visibility. However, as Brooks (1997) has noted, "…while standard instrumentation has served us well, enabling aviation as we see it today, literally thousands of dead souls, victims of aviation catastrophe, offer mute and poignant testimony to its imperfections. The simple, elegant dream of soaring aloft *visually*, *intuitively* – bird-like – remain elusive" (p. 17). Using conventional displays, pilots must integrate information from many separate sources to achieve situation awareness. This integration process can lead to errors, which in some cases can have deadly consequences.

In commercial aviation, over 30% of all fatal accidents worldwide are categorized as controlled-flight-into-terrain (CFIT). In general aviation, the largest accident category is Continued Flight into Instrument Meteorological Conditions (IMC), where pilots with little experience continue to fly into deteriorating visibility conditions and either collide with terrain and/or lose control of their aircraft because of a lack of familiar external cues. Finally, the single largest factor causing airport delays is limited runway capacity and increased air traffic separation required when weather conditions fall below visual flight rule operations. Today, synthetic vision technology may allow this *visibility* problem to be solved with a *visibility* solution, making every flight the equivalent of a clear, daylight operation.

Synthetic vision is a display system that presents a view of the outside world to the flight crew by melding computer-generated scenes from on-board databases and guidance displays, with information derived from on-board sensors that augment the database imagery to provide object detection and improved integrity of the display. Synthetic Vision Systems (SVS) are characterized by the ability to represent visual information and cues that are intuitive and resemble visual conditions with unlimited ceiling and visibility (Figure 1). In terms of safety benefits, synthetic vision may help to reduce many accident precursors including:

- Loss of vertical and lateral spatial awareness
- Loss of terrain and traffic awareness on approach
- Unclear escape or go-around path even after recognition of problem
- Loss of altitude awareness

- Loss of situation awareness relating to the runway environment and incursions
- Unclear path guidance on the surface

Lately, there has been a significant amount of human factors research published on the subject of synthetic vision. Although research has demonstrated the efficacy of synthetic vision to reduce CFIT accidents, runway incursions, spatial disorientation, and enhance operational capabilities, there remain issues to be investigated by researchers. Therefore, the purpose of the panel is to allow researchers from government, industry, academia, and military to share their perspectives on the human factors of synthetic vision.

NASA Synthetic Vision Perspective for Commercial and General Aviation Aircraft

Lawrence J. Prinzel III, Ph.D.

Meeting national aviation safety goals will require mitigating or eliminating the etiologies of accidents. A significant factor involved in many commercial and general aviation accidents is limited visibility. NASA initiated a new research project to develop technologies to help overcome safety problems associated with limited visibility. The NASA Synthetic Vision System (SVS) project is based on the premise that better pilot situation awareness during low visibility conditions can be achieved by reducing the steps required to build a mental model from disparate pieces of data through the presentation of how the outside world would look to the pilot if their visibility were not restricted. SVS display concepts employ computer-generated terrain imagery, on-board databases, and precise position and navigational accuracy to create a three dimensional perspective presentation of the outside world, with necessary and sufficient information and realism, to enable operations equivalent to those of a bright, clear, sunny day regardless of the outside weather condition.

Several panelists argue that synthetic vision may enhance situation awareness but have significant concerns and question whether synthetic vision is the right solution. While agreeing for the need for more research, the government perspective is that synthetic vision is much more than just the display of synthetic terrain and that safeguards can be implemented to ensure that such concerns do not plague synthetic vision systems. The NASA Synthetic Vision System is composed of several technologies that include synthetic vision head-down, head-up, and navigation displays; pathway and guidance symbology; runway incursion prevention technology; database integrity monitoring equipment; enhanced vision sensors; taxi navigation and surface maps; and advanced communication, navigation, and surveillance. Together, these technologies represent a comprehensive solution to problems of restricted visibility --- i.e., solving a *visibility* problem with a *visibility* solution. The presentation will describe several synthetic vision systems that are being developed for commercial, business, and general aviation aircraft. An overview of research will also be provided that demonstrates the potential of SVS to mitigate the precursors to low-visibility accidents and significantly enhance operational capabilities.

Industry Perspective for Business and Regional Aircraft

Tim Etherington

Perspective flight displays have been widely researched for over 50 years. Widespread availability of accurate database information and new survey techniques coupled with advances in mass storage and graphics processing have finally enabled the application of this research to practical avionics architectures. Processing power is never unlimited and storage is still not free so the question of minimum requirements for synthetic vision systems is explored. These requirements are discussed for minimum resolution of terrain data, texturing of the terrain frame and shading applied to the texture. Field of view requirements, guidance concepts, relationship to required navigation performance, precision navigation and database validation issues are discussed. The industry perspective is explored for the business and regional aircraft market with possible operational benefits detailed.

Synthetic Vision Technology for Air Force Applications

Guy A. French, Ph.D.

Synthetic vision technologies may include databases of terrain, obstacles, threats, traffic, and weather information that are rendered on one or more displays to aid the pilot in creating and maintaining an accurate mental model of the aircraft situation relative to the environment outside the cockpit. While the current location for displaying information to aircrew is primarily on multifunction displays, increasingly both commercial and military flying organizations are turning to head-up or head-mounted displays due to their "see through" nature. As these displays become more common, information beyond that required for basic flight will begin to find its way onto the HUD and HMD leading to potential conflict between the desire to provide more information and the desire to see through to the outside world. Various symbology and formatting strategies may be employed to reduce or resolve this conflict.

Another potential issue is that the underlying databases are likely to have widely varying update cycles due to the nature of the specific information each contains. Within the civil airspace processes and procedures will be developed that allow for regular maintenance of database accuracy. In areas with a more austere nature that might be of interest to USAF operators on short notice (e.g. open fields with no instrumentation) such database maintenance is likely to be less frequent and/or complete. There are several strategies that may be employed to ameliorate stale data in these remote locations, including ground support teams, UAVs, and enhanced vision systems.

Synthetic Vision Industry Perspective for Large Transport Aircraft

Michael P. Snow, Ph.D.

Synthetic vision, the concept of displaying a forward view to the pilot based on a database, has been researched and developed for several decades. It usually includes egocentric, perspective view of commanded flight path with terrain, obstacle, traffic, airspace and other data. Research findings indicate that use of these displays leads to greater pilot situation awareness, reduced workload, and reduced flight technical error. Proposed benefits include increased safety and new operational capabilities such as reducing approach minima and aircraft separation. The application of this technology in large transports is discussed, emphasizing pragmatic reasons for including it in modern commercial flight decks – or not. Obstacles to application in this environment include cost, cost-effectiveness and maturity of competing technologies, required infrastructure and technology development, training impacts, regulatory concerns, and remaining human factors issues. These are detailed and areas in which human factors professionals might make an impact are outlined.

Situation Awareness and Synthetic Vision

Mica R. Endsley, Ph.D. and William M. Jones

Synthetic Vision Systems (SVS) are built on database-derived information that is used to aid the pilot in visualizing the aircraft situation relative to information outside the cockpit. It may incorporate terrain, obstacles, cultural features, weather, and/or traffic information. As an additional and intuitive source of information, the SVS concept may aid pilot situation awareness (SA) in many ways. Due to the limitations of display technology, however, it may also lead to certain SA difficulties, particularly if it is used in place of out-of-the-window viewing under no or low visibility conditions. The many potential improvements in pilot SA that can be enabled through SVS include:

- Overcoming CFIT-inducing problems,
- Augmented information for basic flight control,
- Improved awareness of other traffic, and
- Aiding in flight operations tasks such as:

- Evaluation of changes in runway and approach
- Evaluation of new ATC vector/clearance
- Evaluation of aircraft spacing
- Evaluation of timing and fuel usage on path
- Awareness of poor weather conditions on route.

Along with these benefits, however, there are hidden traps that may undermine SA unless the SVS systems are carefully designed and tested. These pitfalls include:

- Difficulty in correctly perceiving the vertical flight profile in a 3D display,
- The compelling influence of graphical 3D displays may overcome digitally presented instrument data, leaving the pilot open to spatial disorientation,
- The potential to believe no traffic (or other obstacles) are present if not displayed (type II errors), when in fact this "false world" could result from a database or sensor limitation.

Although the veridical nature of the SVS display is its strong point— integrated information presented in a very natural manner — this also is its Achilles' heel. It is a far more compelling display than any previously and more likely to suck pilots into any false or ambiguous information it presents. While it can be easily argued that the information provided by the SVS is better than the very limited information available today under low visibility conditions, the desire to increase aircraft throughput (and reduce safety margins) under these conditions by use of the SVS (creating significant efficiency gains), demands that any potential SA problems be detected in the evaluation process and corrected for prior to its implementation in flight operations.

Compellingness and Synthetic Vision Systems

Christopher D. Wickens, Ph.D.

Endsley and Jones (this symposium) have made a "compelling" case for the advantage of SVS displays to support terrain and flight path awareness, but have also alluded to the "hidden traps" associated with the very compellingness of the display itself, in terms of overtrust of the information offered there, and over-allocation of attention to that display. This paper will undertake a careful examination of the components that induce compellingness in an SVS display: its photo-realism, its 3D egocentric frame of reference, and the pathway guidance, which it often hosts. We will consider the implications of excessive attentional tunneling on the display for the detection of off-normal events, and will summarize the existing data on SVS, and similar systems, regarding the allocation of attention, and the detection of unexpected events.

Human Factors Analysis Evaluation of SVS Commercial and Business Systems

Kevin M. Corker, Ph.D. & Eromi Guneratne

We have analyzed one of the Aviation Safety Program's interventions for safety, the Synthetic Vision System for commercial and business jet (SVS-CAB) applications from a human performance/human factors perspective. In performing that analysis, we identified categories of human factors issues associated with the use of the technology as follows:

- Visual presentation of information (e.g., compellingness, visual momentum and cross-reference to other instrumentation)
- Integration of several types of information into the SVS Display and integration for the SVS with either out-the-window or other flight directive and navigational data available in the cockpit (flight directive, predictive, terrain, traffic.),
- Procedures for use of the technology (crew resource management)

- Off-nominal or marginal operations

An analysis of these issues as applied to the SVS design was undertaken to determine the current state of the art associated with human system interaction in similar or analog systems. This examination yielded a document of "issues" associated with the presentation of flight guidance and terrain avoidance and awareness in low or marginal visibility conditions. The state of the art was then compared with the state of research and development of the SVS-CAB to produce a matrix of features of the visual-aiding system mapped to the current state of knowledge about the human perceptual, cognitive and procedural performance with such systems. This matrix provided rough estimates of the state-of-knowledge and the functional features of the system on a three level scale: indicating first that the state of knowledge was adequate and those principles well integrated into the design, or indicating some gaps in the state of knowledge and correspondingly possible gaps in the system design, and finally indicating either a lack of knowledge or a lack of currently observable consideration in the design. The results of these analyses will be provided in this panel discussion.

References

Brooks, P.E. (1997). Highway in the sky: Our legacy is safety on the road ahead. Flightline, July/August, 16-22.

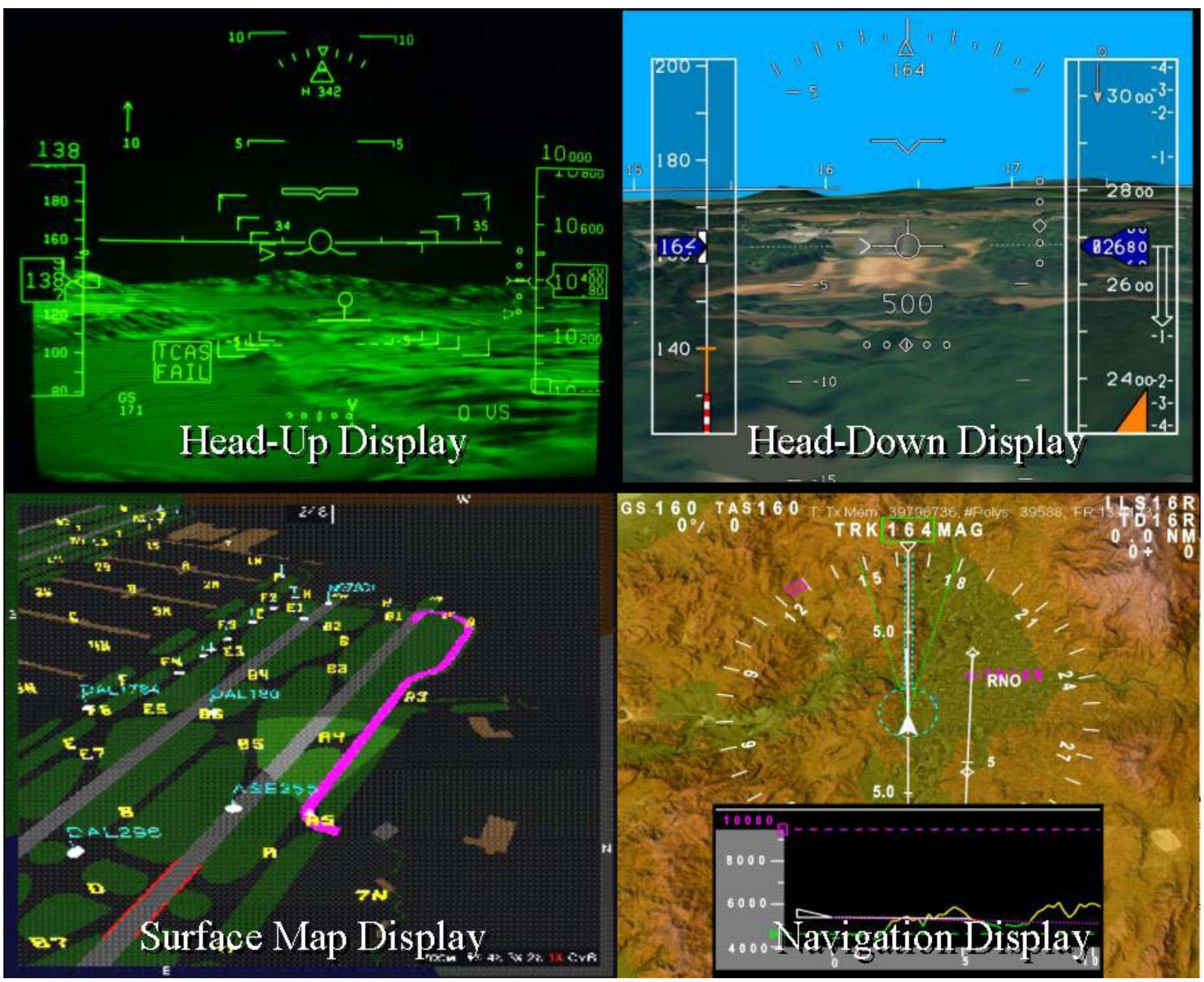

Figure 1. Examples of Synthetic Vision and Advanced Navigation Displays