DOT/FAA/AM- 26/01

Office of Aerospace Medicine

Washington, D.C. 20591

Operational and Human Factors Considerations for Synthetic Vision Systems and Head-worn Displays: Results from a Literature Review and Survey

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January 2026

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Technical Report Documentation

<table>
<tr><td colspan="2">1. Report No.
DOT/FAA/AM-26/01</td></tr>
<tr><td rowspan="2">2. Title & Subtitle
Operational and Human Factors Considerations for Synthetic Vision Systems and Head-worn Displays: Results from a Literature Review and Survey</td><td>3. Report Date
January 2026</td></tr>
<tr><td>4. Performing Organization Code
AAM-510</td></tr>
<tr><td>5. Author(s)
Kelene A. Fercho[1], Bryan L. Watson[2], Dennis B. Beringer[2], Theodore C. Mofle[2], Matthew Scheinblum-Brewer[3]</td><td>6. Performing Org Report Number
Not applicable</td></tr>
<tr><td>7. Performing Organization Name & Address
[1]Flight Technologies and Procedures Division
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Embry-Riddle Aeronautical University
1 Aerospace Boulevard
Daytona Beach, FL 32114</td><td>8. Contract or Grant Number
Not applicable</td></tr>
<tr><td>9. Sponsoring Agency Name & Address
Office of Aerospace Medicine
Federal Aviation Administration
800 Independence Ave., S.W.
Washington, DC 20591</td><td>10. Type of Report & Period Covered
Technical Report</td></tr>
<tr><td colspan="2">11. Supplementary Notes
Not applicable</td></tr>
<tr><td colspan="2">12. Abstract
This research addressed operational considerations from a human factors perspective for the use of synthetic vision systems (SVSs) implemented on a head-worn display (HWD). Given the increasing use and development of SVSs and aviation HWDs, Federal Aviation Administration stakeholders requested information to identify gaps in knowledge to inform future research requirements, and to identify criteria not presently contained in applicable regulations for pilot training and for evaluating equipment functionality, intuitiveness, and potential hazards. This paper includes an overview of commercially available combined vision systems, enhanced vision systems, and SVSs implemented on an HWD; an overview of published scientific literature on SVSs implemented on an HWD; and results from a survey of 70 individuals who reported moderate or greater familiarity with SVSs or HWDs. The purpose of the survey was to solicit expert opinion on industry interest, and on human factors and operational considerations of SVSs implemented on an HWD. Example training topics for the use of SVSs implemented on an HWD are included in the Appendix.</td></tr>
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13. Key Word		14. Distribution Statement	
Combined Vision System, Enhanced Vision System, Head-mounted Display, External Vision System, Head-worn Display, Human Factors, Literature Review, Pilot Training, Questionnaire, Survey Research, Synthetic Vision System, Synthetic Vision Guidance System		Unlimited	
15. Security Classification (of this report)	**16. Security Classification (of this page)**	**17. No. of Pages**	**18. Price**
Unclassified	Unclassified	136	Not applicable

Author Note

Funding	This report was completed with funding from the FAA Human Factors Division (ANG-C1) in support of the FAA Office of Aviation Safety (AVS), Flight Standards Service (AFS-400).
Conflicts of Interest	None
Author Contributions	KAF: Conceptualization, Literature Review, Survey Methodology, Data Collection, Data Analysis, Writing, Interpretation of Results, Visualizations, Project Administration. DBB: Literature Review, Market Research, Writing. BLW: Survey Methodology, Data Collection, Interpretation of Results. TCM: Data Analysis, Interpretation of Results, Visualizations. MSB: Literature Review, Market Research, Writing.
Data Availability	De-identified summary and raw survey data are presented in this report. Additional requests may be sent to kelene.a.fercho@faa.gov

Acknowledgments

We would like to thank the sponsor of this research, Scott McLellan, and the program manager, Dr. Victor Quach. We would also like to thank Janine King-Lane and Suzanne Thomas for assistance with participant recruitment and project management; Dr. Peter Hu, Dr. Teena Sanders, and Dr. Casey Yetter for editing and organizing the results of the survey; Sierra Corbin for organizing the literature review results; and Sean Flack, Eddie Austrian, and Hanna Forbat for their helpful feedback on earlier versions of the paper. We would also like to thank the Lemasters Group and Brian Townsend for support with participant recruitment. Most importantly, we would like to thank the survey participants who volunteered their time and shared their expertise with us.

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List of Abbreviations

2D	Two-dimensional
3D	Three-dimensional
ADS-B	Automatic Dependent Surveillance–Broadcast
AFM	Airplane flight manual
AI	Artificial intelligence
ALS	Approach lighting system
AOA	Angle of attack
ASA SVS	Aircraft state awareness synthetic vision system
ATAK	Android Team Awareness Kit
ATC	Air traffic control
ATP	Airline transport pilot
BIRDTAM	Bird strike risk or warning NOTAM
CAMI	Civil Aerospace Medical Institute
CAT I	Category I
CAT II	Category II
CBT	Computer-based training
CFIT	Controlled flight into terrain
C.F.R.	Code of Federal Regulation
CPDLC	Controller–pilot data link communications
CRM	Crew resource management
CVS	Combined vision system
DA	Decision altitude
DAL	Design assurance level
DH	Decision height
DVE	Degraded visual environment
EBT	Evidence-based training
EFB	Electronic flight bag
EFVS	Enhanced flight vision system

EGPWS	Enhanced Ground Proximity Warning System
EMM	Electronic moving map
ETSO	European Technical Standards Order
EVS	Enhanced vision system
FAA	Federal Aviation Administration
FD	Flight director
FFS	Full flight simulator
FLIR	Forward-looking infrared
FMS	Flight management system
FOR	Field of regard
FOV	Field of view
FPARC	Flight path angle reference cue
FPM	Feet per minute
FPV	Flight path vector
FTD	Flight training device
GA	General aviation
GPS	Global Positioning System
GPWS	Ground Proximity Warning System
GS	Glideslope
HAA	Helicopter air ambulance
HDD	Head-down display
HEMS	Helicopter emergency medical service
HGS	Head-up guidance system
HITS	Highway in the sky
HTAWS	Helicopter Terrain Avoidance and Warning System
HUD	Head-up display
HWD	Head-worn display
HMD	Helmet-mounted display
IAP	Instrument approach procedure

IFR	Instrument Flight Rules
ILS	Instrument landing system
IMC	Instrument meteorological conditions
IR	Infrared
JHMCS	Joint Helmet Mounted Cueing System
LDA	Landing distance available
LP	Localizer performance
LPV	Localizer performance with vertical guidance
LVO	Low visibility operation
LVP	Low visibility procedure
MAP	Missed approach point
MDA	Minimum descent altitude
MFD	Multifunction display
MMI	Man-machine interface
MMEL	Master minimum equipment list
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NIR	Near-infrared
NNC	Non-normal checklist
NOTAM	Notice to Airmen
OAM	Office of Aerospace Medicine
OEI	One engine inoperative
OEM	Original equipment manufacturer
OTW	Out the window
PAPI	Precision approach path indicator
PDU	Primary display unit
PF	Pilot flying
PFD	Primary flight display
PFI	Primary flight information

PM	Pilot monitoring
RA	Resolution advisory
RAAS	Runway Awareness and Advisory System
RFM	Rotorcraft flight manual
RNAV	Area navigation
ROAAS	Runway Overrun Awareness and Alerting System
RVR	Runway visual range
SA	Special authorization
SID	Standard instrument departure
SMGCS	Surface Movement Guidance and Control System
SOP	Standard operating procedure
STC	Supplemental type certificate
SV	Synthetic vision
SVS	Synthetic vision system
SVGS	Synthetic vision guidance system
TA	Traffic advisory
TAK	Team Awareness Kit
TASE	Training areas of special emphasis
TAWS	Terrain avoidance and warning system
TCAS	Traffic alert and collision avoidance system
TRL	Technology readiness level
UAS	Uncrewed aircraft system
U.S.	United States
USAF	United States Air Force
VASI	Visual approach slope indicator
VFR	Visual flight rules
VMC	Visual meteorological conditions
WAAS	Wide Area Augmentation System
XVS	External vision system

Executive Summary

This research addressed operational considerations from a human factors perspective for using synthetic vision systems (SVSs) implemented on a head-worn display (HWD). Given the advancements in both the development and use of SVSs and aviation HWDs, Federal Aviation Administration (FAA) stakeholders requested information to identify gaps in knowledge to inform future research requirements, and to identify criteria not presently contained in applicable regulations for pilot training and evaluating equipment functionality, intuitiveness, and potential hazards. To address these aims, this paper includes an overview of commercially available combined vision systems (CVSs), enhanced vision systems (EVSs), and SVSs implemented on an HWD; an overview of published scientific literature on SVSs implemented on an HWD; and results from a survey of 70 individuals with a self-reported level of familiarity of moderate or greater with SVSs or HWDs. The Appendix contains examples of potential training topics.

Current State and Future Directions of Synthetic Vision Systems Implemented on Head-worn Displays. At least two air carriers outside of the United States (U.S.) are currently conducting flight operations with a CVS displayed on an HWD, though neither utilizes a SVS by itself. At least four avionics original equipment manufacturers (OEMs) currently offer an aviation HWD, though none utilize SVS by itself; three are used for a CVS, and one for mixed reality, including real-time imagery and augmented reality. Based on the results of an anonymous survey of avionics OEM representatives, several respondents who do not currently offer EVS, CVS, SVS, or an external vision system (XVS) on an HWD reported plans to offer at least one of these options on an HWD within the next 1-6 years. Similarly, survey results of aircraft operators or air carrier representatives indicated that several respondents planned to acquire an HWD in the next 10 years for use with SVS, CVS, and EVS. Overall, survey results suggested that there is aviation industry interest in HWDs for use during flight operations, though it may be easier to make a business case for EVSs and CVSs given existing FAA regulations and policy for enhanced flight vision system (EFVS) operations. Some survey respondents mentioned the need for proof of market acceptance and the need for operational credit before pursuing SVS technology implemented on an HWD.

Overview of Synthetic Vision Systems Implemented on Head-worn Displays Research Literature. A literature search identified 159 research articles relevant to aviation SVSs, of which 10 focused specifically on SVSs or XVSs (with EVS and SVS information) implemented on an HWD. All 10 articles provided results from human-in-the-loop experiments conducted in a flight simulator with aircraft pilot participants. Eight articles were focused on fixed-wing operations, and two articles were focused on rotorcraft operations. Six of the studies examined approach and landing operations, four examined taxi operations, two examined unusual attitude recognition and recovery, one examined departure operations, one examined en route operations, and one examined hover maneuvers. For the two rotorcraft-focused articles, the themes were related to helicopter offshore operations, including using an XVS on an HWD to compensate for the lack of visual cues over water surfaces, adverse visual motion over water surfaces, methods to model the synthetic ocean surface, and the effect of different three-dimensional (3D) perspective views. For the eight fixed-wing-focused studies, the themes were related to SVS display type (head-up display [HUD], HWD, head-down display [HDD]); symbology design (size, color, pathway guidance symbology); HWD ergonomics (weight, balance, and comfort); monocular optics; ambient vision that provides an unlimited field of view

(FOV); SVS image quality (resolution, brightness, contrast, clutter, occlusion, latency); SVS display color (monochrome and colorized); and comparison to traditional sources of information (paper charts, two-dimensional [2D] track-up moving map electronic flight bag, existing flight deck displays). Scenarios were included to evaluate the effectiveness of an SVS on an HWD to prevent controlled flight into terrain (CFIT) accidents, taxi incursions, unusual attitude recognition and recovery, and during approaches to closely spaced parallel runways.

The results from these studies can be grouped into themes. Several studies noted concerns with participant comfort, such as reports of pressure points, hot spots, and eye strain (Arthur et al., 2004; Arthur et al., 2008; Arthur et al., 2017; Nicholas et al., 2019), suggesting that factors such as HWD weight, size, balance, and comfort are important human factors issues. Topics related to SVS symbology and imagery formed a second major theme. For example, results from one study suggested that the size and color of traffic symbology influenced detection rates for taxi incursion events (Arthur et al., 2007). Symbology brightness, contrast, intuitiveness, and image resolution were also identified as important design considerations (Arthur et al., 2004; Arthur et al., 2007; Arthur et al., 2011; Arthur et al., 2017). A third theme was related to SVS display types, such as comparing SVSs implemented on HUDs, HDDs, and HWDs. In general, the SVS display type did not have an operationally significant effect on flight performance metrics. For example, when flying a circling maneuver in a terrain-challenged environment, display type (SVS on a HUD, HWD, or HDD) did not have a significant effect on vertical or lateral navigation path performance (Arthur et al., 2004). In a second study, participants were able to recover from unusual attitude scenarios when using SVS on an HDD or HWD (Arthur et al., 2017). In a third study, approach and touchdown performance metrics were not reliably different across SVS display types (HUD, HWD, or HDD; Beringer, 2020). A fourth theme was related to the effect of different sources of information. For example, SVSs on an HWD were compared to other sources of information, such as a 2D track-up moving map electronic flight bag (EFB), paper chart, HUDs, and existing flight deck displays (Arthur et al., 2006; Arthur et al., 2007; Arthur et al., 2008; Nicholas et al., 2019). Results from these studies suggested that in some cases, there were no significant performance differences based on the information source, and other times, there was an operational benefit for the more advanced electronic display. The two rotorcraft studies were task-specific to offshore operations such as hovering near a wind turbine or approaching an offshore platform (Ernst et al., 2018, 2019). Results from these studies suggested that XVS implemented on an HWD offered a promising solution for counteracting hazards related to the lack of visual cues over an ocean surface and modeling wind and motion cues on an ocean surface. Overall, results from the SVS HWD research identified the importance of display design, and that SVSs displayed on HWDs have the potential to support the pilot or flight crew during several flight tasks and phases of flight.

Survey of Expert Opinion on Human Factors and Operational Considerations for Synthetic Vision Systems Implemented on Head-worn Displays. The purpose of this research was to survey expert opinion on industry interest, and on human factors and operational considerations of SVSs implemented on an HWD. Responses to both multiple-choice and free-response questions were obtained from 70 respondents with a self-reported moderate or greater familiarity with SVSs or HWDs. Of the 70 respondents, 31.4% (n = 22) worked for a government agency; 25.7% (n = 18) worked for a company that designs, manufactures, supplies, or services avionics systems; 25.7% (n = 18) worked for a company that designs and manufactures aircraft; 12.9% (n = 9) worked for an aircraft operator or air carrier; 2.9% (n = 2) identified as an advanced vision subject matter expert consultant or worked for a software company that designs and develops electronic flight bag software; and 1.4% (*n* = 1) reported that they were a pilot but did not work in the aviation industry. Expert respondents identified benefits of SVSs, such as enhanced situation awareness and a safety or operational benefit for different types of flight operations, including non-precision and precision approaches (i.e., Category I and Category II); different phases of flight, including approaches, landings, and missed approaches; and different operating environments such as nighttime operations. Experts also identified safety or operational benefits of SVSs for Visual Flight Rules (VFR) operations, such as terrain and obstacle awareness, and orienting to an airport in an urban environment when the runway may be more difficult to acquire visually. Expert concerns with SVSs centered on the accuracy of terrain and obstacle database information, susceptibility to the Global Positioning System (GPS) spoofing or jamming, and display clutter or colorization. Specific to an SVS on an HWD, concerns were related to HWD fitment, HWD shifting over time, HWD abrupt movement (e.g., during impact with the ground during a balked landing), and pilot comfort. In addition, Expert respondents mentioned concerns with the effects of monocular and binocular optics; the potential for increased risk-taking behavior; view conformation; the potential for visual distraction and confusion; blocking or obscuring the real-world scene; and operational concerns such as donning an O_2 mask and the practicalities of routine HWD maintenance. Training recommendations centered on emphasizing system limitations; simulator training for engine failures at different reference speeds; crew coordination; the importance of maintaining an effective visual scan; symbology and runway markings; display controls and adjustments; traffic and obstacle identification; and the effect of the field of regard for different phases of flight.

Appendix. The Appendix contains examples of potential training topics for the following areas: hardware and software; ergonomics; aircraft flight information, symbology, and imagery; abnormal, non-normal, and emergencies; associated systems and components; crew coordination procedures; ground training; preflight; taxi; takeoff; climb; cruise; descent; approach; landing; rollout; missed approach; balked landing; and post-flight. These examples are not FAA-required areas of training, but are provided as examples of key themes identified through the literature review, survey study, subject matter expert consultation, and a review of technical standards documents.

1.0 Introduction

As synthetic vision systems (SVSs) continue to be developed and utilized, it's essential to identify and understand the human factors and operational considerations involved. This understanding is crucial for safely integrating these technologies into aircraft and the broader United States (U.S.) National Airspace System (NAS). This paper is in response to a request from Federal Aviation Administration (FAA) stakeholders for information to identify gaps in knowledge on SVSs as implemented on a head-worn display (HWD). The goal is to guide future research needs and identify criteria not currently covered in existing regulations for pilot training, as well as to assess equipment functionality, intuitiveness, and potential hazards. The purpose of this research was to review the published literature and gather information from original equipment manufacturers (OEMs), domestic and international operators, FAA field personnel, and aviation organizations to understand the state of SVSs implemented on HWDs, potential changes, and operational implications from a human factors perspective. The primary focus of this work included transport category airplanes and Title 14, Part 121 of the Code of Federal Regulations (C.F.R.) flight operations, though other aircraft and flight operations are mentioned. This paper includes an overview of commercially available combined vision systems (CVSs), enhanced vision systems (EVSs), and SVSs implemented on HWDs; an overview of published scientific literature on SVSs implemented on HWDs; results from a survey of 70 individuals with a self-reported level of familiarity of moderate or greater with SVSs or HWDs; and an Appendix with examples of training topics for SVSs implemented on HWDs.

1.1 Descriptions of Synthetic Vision Systems, Enhanced Vision Systems, Combined Vision Systems, External Vision Systems, and Head-worn Displays

The FAA distinguishes between SVSs, synthetic vision guidance systems (SVGSs), and aircraft state awareness synthetic vision systems (ASA SVSs), and their uses and operational credit through FAA Orders and Advisory Circular (AC) guidance. For example, according to AC 20-185A:

> Pursuant to 14 C.F.R. § 1.1, Synthetic Vision means a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features. Synthetic Vision Systems are an electronic means to display a synthetic vision image of the external scene topography to the flight crew. Synthetic vision's key features can also be applied to Synthetic Vision Guidance Systems, which enable instrument approaches with lower decision altitudes, and aircraft state awareness synthetic vision systems, which improve the pilot's awareness of the aircraft's attitude and energy state (p. 2-1).

All types of SVSs depict a synthetic vision image on an electronic display, such as a head-up display (HUD), a head-down primary flight display (PFD), or an HWD; currently, SVSs are most often implemented on a head-down PFD. For simplicity, in this paper, we use SVS to refer to any type of SVS, while acknowledging there are important distinctions among SVSs, SVGSs, and ASA SVSs.

Approved operators may use SVSs during flight operations; example use cases include low visibility conditions/operations for credit (specific to SVGS) or as a safety enhancement. For example, FAA Order 8400.13F CHG 1 authorizes Special Authorization (SA) Category I (CAT I) approaches with a decision height (DH) as low as 150 feet and a visibility minimum as low as Runway Visual Range (RVR) 1400 feet on suitable instrument landing system (ILS) equipment at runways with reduced lighting. These operations require the use of airborne equipment in accordance with AC 120-118, and the list of airborne systems includes SVGS; see also Operations Specification (OpSpec) C059: SA CAT I Instrument Approach and Landing Operations. SVSs may support a pilot in safely and efficiently maneuvering in terrain-challenged or low-visibility conditions. In addition, SVSs often integrate information from other aircraft systems, such as a Terrain Avoidance and Warning System (TAWS) or Traffic Alert and Collision Avoidance System (TCAS) on the SVGS display. Together, these features have the potential to enhance the development and maintenance of pilot situation awareness by supporting the pilot with the process of continuously integrating information from situation assessments during the dynamically changing flight operation.

Enhanced vision systems, CVSs, and external vision systems (XVSs) are other types of flight deck technologies that also provide a depiction of the external visual scene on a display. These flight deck technologies are distinguishable based on the source of information used for the external scene depiction, the characteristics of the displayed image, and their use during low-visibility conditions/operations for credit or as a safety enhancement. According to 14 C.F.R. § 1.1, an enhanced flight vision system (EFVS) means:

> …an installed aircraft system which uses an electronic means to provide a display of the forward external scene topography (the natural or manmade features of a place or region especially in a way to show their relative positions and elevation) through the use of imaging sensors, including but not limited to forward-looking infrared, millimeter wave radiometry, millimeter wave radar, or low-light level image intensification. An EFVS includes the display element, sensors, computers and power supplies, indications, and controls (p. 8).

Additional details on equipment requirements and operating rules for EFVS are provided in 14 C.F.R. § 91.176. For simplicity, we use EVS to refer to any type of EVS technology, while acknowledging that there are important distinctions between EVSs and EFVSs. CVSs include aspects of both SVSs and EVSs and merge an EVS and SVS image into a single view. According to AC 20-167A:

> Some examples of a CVS include database-driven synthetic vision images combined with real-time sensor images superimposed and correlated on the same display. This includes selective blending of the two technologies based on the intended function of the vision system for which approval is sought. For example, on an approach, most of the arrival would utilize the SVS picture. As the aircraft nears the runway, the picture gradually and smoothly transitions from synthetic to enhanced vision, either for SVS picture validation or displaying the runway environment (p2-5).

The intended function of a CVS depends on its intended use and associated airworthiness requirements (e.g., SVGS or EFVS). Finally, an XVS is an emerging technology that is “a combination of display, sensor, and computing technologies which create an electronic view, forward of the cockpit, analogous to forward-facing windows” (Kramer et al., 2018). An XVS may include information from an SVS, EVS, CVS, other types of external sensors, or even video imagery of the external scene.

The FAA defines a head-mounted display as “a special case of head-up display mounted on the pilot’s head” (AC 25-11B). SAE describes an HWD by stating that they “provide navigation, control and primary flight guidance information including terrain and obstacle avoidance” (SAE ARP6377, 2023). For this paper, we use the term HWD rather than head-mounted display. HWDs have been in use for several decades for military aviation applications, and more recently, interest in this technology has increased in the civil aviation sector. HWDs provide many of the same capabilities as a head-up guidance system (HGS) or HUD, including the display of aircraft flight information and symbology to the pilot in the line of their external forward vision. An HWD may be an appealing display option, such as when space within the flight deck is limited. HUDs require significant overhead volume for the projector, which means some aircraft lack the required overhead space to support an HUD installation. HWDs also add significantly less weight to the aircraft than an HUD. Further, there is the potential for lower acquisition and flight deck integration costs compared to other display types (FAA, 2022). Because SVS, EVS, CVS, and XVS can be combined with a head-down display (HDD), HUD, or HWD, there may be situations in which an HWD is the preferred display type for these flight deck vision system technologies.

2.0 Current State and Future Directions of Synthetic Vision Systems Implemented on Head-worn Displays

In this section, we provide an overview of currently available HWD technology capable of displaying EVS, SVS, CVS, or XVS imagery. This information was obtained from public sources and may be outdated in the future. The reader is encouraged to verify information with the OEM.

2.1 Brief History of Head-worn Displays

If we examine the development of HWDs (and their military parallel, helmet-mounted displays [HMDs]), we can see that many of the devices fielded in the past (i.e., almost exclusively military applications) presented flight data to the pilot and/or graphical targeting data for ordinance delivery. In more recent applications, they have presented an adjunct display for the HUD. These have appeared in numerous military combat aircraft, box-fixed-wing and rotorcraft. More recently, an effort has been made to replace the HUD with an HMD that presents vision system imagery. As such, the F-35 is the first combat aircraft in approximately 50 years to not have a HUD, having been replaced by the HMD (Keller, 2023). It should be mentioned that military mission applications are different to a large degree from civil operations and that there is a difference in acceptable risk related to operations. This may be why military applications were seen much earlier, tailored to specific tasks.

Recent FAA research attempted to demonstrate that an HWD could be used as an equivalent to a HUD for flight operations in the U.S. NAS (Beringer, 2020). Those, however, were not presenting synthetic vision (SV) imagery in the displays but only aircraft flight information and symbology equivalent to that found in an already-certified HUD. Several initiatives, mentioned later, involved displays that were SV-capable. These efforts were, for the most part, related to civil transport and fixed-wing aircraft. Other parallel developments occurred for rotorcraft in a slightly time-lagged fashion. Thales Group S.A. has been developing and continues to develop HWDs, notably its TopMax, which is a monocular[1], full-color CVS HWD for fixed-wing aircraft. They also offer the monocular, full-color Scorpion CVS HWD, and the binocular, full-color TopOwl CVS HWD for military fixed-wing and rotary-wing aircraft applications. As of 2022, Universal Avionics (now Elbit Systems) was preparing to provide its ES4000 cameras, capable of providing several types of imagery, including enhanced and SV, for use in the Airbus H145 helicopter (Devitt, 2022). Elbit Systems has also entered the market with the X-sight HMD (i.e., wide field of view [FOV], color, binocular), which is SV-capable.[2] Thus, the effort to deploy SV-capable systems can now be seen across the board.

Thurber (2020) reported that EASA had awarded the first civil certification for the Universal Avionics Skylens (i.e., SV-capable). In 2023, the FAA Aircraft Certification Service issued AerSale, Inc. a Supplemental Type Certificate (STC) for the AerAware EFVS on Boeing 737-600/-700/-800/-900 Series aircraft (STC No. ST04576AT). This is the first FAA-certified HWD in the U.S. market that provides the captain and first officer on a transport category aircraft with a vision system on two HWDs. In 2024, the FAA Flight Standards Service evaluated EFVS operations with the AerSale AerAware EFVS and determined it to be operationally suitable for use during EFVS operations under Title 14 of the Code of Federal Regulations (14 C.F.R.) § 91.176(a) and § 91.176(b).

2.2 Current and Potential Future Head-worn Display Uses

Currently, at least two air carriers outside of the U.S. are conducting flight operations with advanced vision HWDs: Aurigny Air Services Ltd. in the Channel Islands and Drukair – Royal Bhutan Airlines based in the Himalayan Kingdom of Bhutan. At the time of writing, both air carriers have used the Universal ClearVision system on ATR turboprop aircraft for several years. Aurigny Air Services reported that the use of the Universal ClearVision system has resulted in an increased number of landings completed in low-visibility conditions that would have otherwise been diverted (BBC News, 2024). It should be noted that although the Universal Avionics ClearVision system can merge an EFVS view with a synthetic three-dimensional (3D) terrain SVS view, both airlines operate with enhanced vision only.

Additional task-specific applications are being considered for HWD technology. Suggested uses include aerial firefighting using EFVS and possibly SVS (Gallagher, 2021; AerialFire Staff, 2024); supersonic transport aircraft (Ruvolo, 2024); law enforcement (Devitt, 2022); and remotely operated semi-autonomous air vehicles (inferred as early as 1973 in the movie Westworld, in which a remote human operator wears an HWD to operate a large hovercraft-type passenger-transport vehicle). A current use of an HWD is to provide an on-vehicle first-person view for drone racing, but this is more related to what could more appropriately be called EFVS, not SVS per se. Bode Aviation is presently examining the use of sensor-derived data to pinpoint fire targets for water and retardant drops (C. Rice, personal communication, September 2024). Current evaluations of technical solutions for communicating

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[1] A monocular HWD presents information to a single eye. A biocular HWD displays identical information to both eyes. A binocular HWD displays a separate image tailored to each eye's viewing perspective.
[2] http://elbitsystems.com/product/x-sight

fire location and targeting points include the Team Awareness Kit (TAK) app, Android Team Awareness Kit (ATAK). This application uses Global Positioning System (GPS) data on Android phones to allow first responders to track team members. It eliminates reliance on cellular networks. This application has both online and offline maps, allowing users to mark (and thus share) their locations, along with data files relevant to the effort. It also provides for real-time chat or live-stream communications. Efforts are also underway to connect Android tablets by datalink to HMDs. The helmet- or head-mounted displays currently under consideration are commercial-off-the-shelf devices. These displays could be used to overlay the locations of hotspots in the pilot's field of regard, improve awareness of the relative/absolute positions of fire targets, and enhance the timeliness and accuracy of retardant/water delivery to these locations.

Although there thus appear to be many avenues for the expansion of HWD use for a large variety of tasks, the success of such systems will ultimately be related to the ability of the systems to provide adequate display of the important parameters (e.g., accuracy, timeliness, and reliability/survivability), ability to be approved (certified) for the specific use proposed, and affordability (the system on the F-35 is reported to cost approximately $400k; Salas, 2024). The cost of several of the actual display units has decreased, so it may well be the costs of software, installation and maintenance, pilot-training, and the certification process that determine whether the overall cost of these systems will approach affordability. It should be kept in mind that all electronic systems proposed for use on civilian-transport flight decks must "earn" their way onto the flight deck, which generally means the system or device must provide a monetary benefit or address an organizational requirement that outweighs the complete cost of the system. Examples of monetary benefits may include increased throughput from an increased ability to land at more runways or a single runway in reduced visibility, or improved fuel efficiency from a reduction in the number of missed approaches or diversions in reduced visibility. In the civil aviation market, there has been an increased interest in HWDs in recent years (Table 1); however, none of these devices are specifically for SVSs.

Table 1

Commercially Available Civil Aviation Vision System Technology Implemented on a Head-worn Display

Manufacturer and Model	Type of Vision System	Aircraft	Ocular Presentation	Colorization
Honeywell International, Inc. 360 Display	Mixed Reality Including Real-time Imagery and Augmented Reality	Airplane, Rotorcraft	Binocular	Full color
Thales Group S.A. TopMax	EVS, SVS, CVS	Airplane	Monocular (user selectable)	Full color
Universal Avionics ClearVision™ EFVS with SkyLens	EVS, SVS, CVS	Airplane	Binocular	Monochrome green with provisions for color
Universal Avionics ClearVision™ EFVS with SkyVis	EVS, SVS, CVS	Rotorcraft	Monocular	Monochrome

Note. The information in Table 1 was sourced from publicly available materials. Readers are encouraged to confirm the details with the manufacturer.

3.0 Overview of Synthetic Vision System Head-worn Display Research Literature

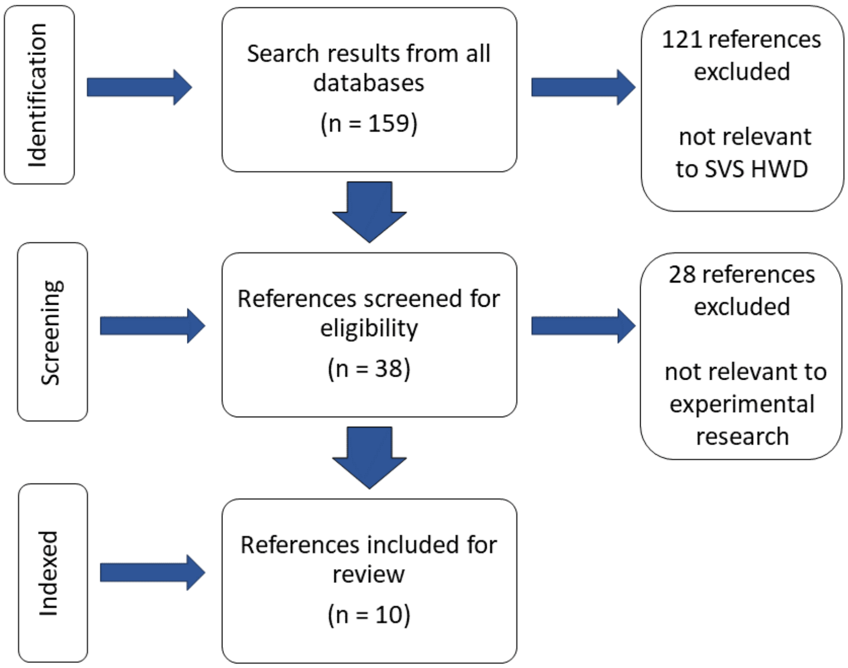
Although research on aviation SVSs dates back at least to the early 1990s, this research has largely focused on SVSs implemented on an HUD or HDD; there are fewer studies that have examined SVSs on an HWD. A review of the research literature on SVSs implemented on an HWD was conducted to synthesize prior research completely and transparently; provide a resource to support the efficient understanding of available research; identify key human factors themes in the research literature; and discern whether previous findings are consistent.

3.1 Method

For this literature review, each article met the criteria provided in the definitions of SVS, HWD, and research. SVS was defined as “an electronic means to display a SV image of the external scene topography to the flight crew” (14 C.F.R. § 1.1). Thus, articles were considered ineligible if the HWD presented synthetic symbology elements but did not also present the external scene topography. AN HWD was defined as a display that presents “information such as aircraft performance and attitude, navigation information, flight guidance symbology (flight director), appropriate crew alerts, traffic, and other information that enable the pilot to monitor, control and maneuver the aircraft” (SAE ARP6377, 2023). Experimental research was defined as “research utilizing randomized assignment of participants to conditions and systematic manipulation of variables with the objective of drawing causal inference” (American Psychological Association, n.d.). Articles were considered ineligible if they were review articles or opinion pieces.

To gather relevant references, an initial search was conducted across eight online databases: Google Scholar, EuroControl, the Defense Technical Information Center repository, FAA Office of Aerospace Medicine (OAM) Technical Reports repository, Volpe Technical Reports repository, the National Transportation Library’s ROSA-P, the National Aeronautics and Space Administration’s (NASA) Technical Reports Server, and the National Technical Reports library. These databases were selected for their relevance and comprehensiveness in covering references across the aviation and human factors disciplines. Keywords related to aviation and SVS were used. The search results were collected from December 2021 to June 2024. No publication date restrictions were placed on the search. References were considered eligible if they were published in English and reported original research. Results from the initial search were aggregated, and duplicates were removed. A full-text search was used to filter for keywords related to HWDs. The final list of articles was reviewed for relevancy; see Figure 1 for a summary of the literature review process.

Figure 1
Overview of the Literature Review Search Process for Synthetic Vision Systems on Head-worn Displays



3.2 Results

This search identified 159 SVS articles, of which 121 articles were excluded as not relevant to HWDs. The 38 remaining articles were reviewed, and 28 articles were excluded as not relevant to experimental research. This process resulted in a total of 10 articles eligible for review.

3.2.1 Study Design, Aircraft, Performer

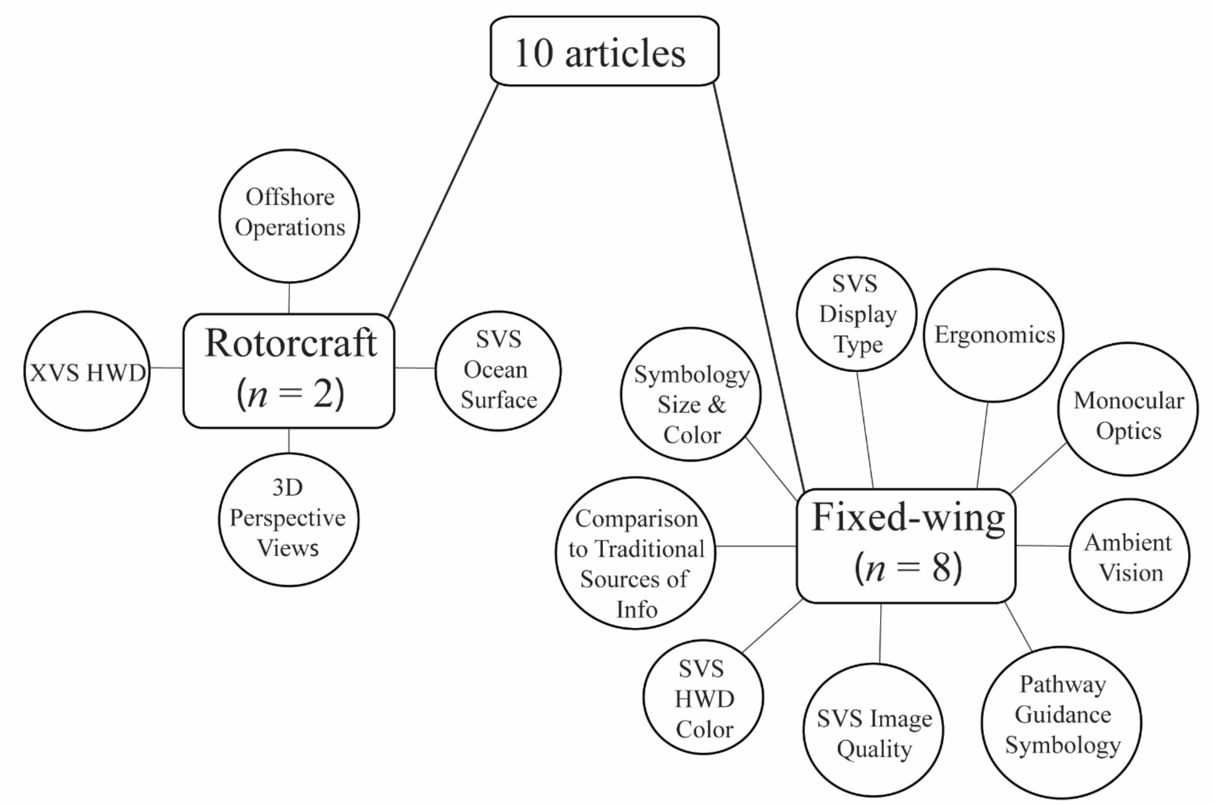
All 10 articles described results from human-in-the-loop experiments conducted in a flight simulator with participants who were reported to be aircraft pilots. In each study, an SVS or XVS implemented on an HWD was used during a simulated flight operation (see Figure 2 for key themes and Table 2 for research article summaries). Eight articles focused on fixed-wing operations, and two articles focused on rotorcraft operations. Of the fixed-wing aircraft studies, seven were conducted in a transport category aircraft flight simulator, and one study was conducted in a general aviation (GA) aircraft flight simulator. Each article focused on one or more phases of flight. Six studies examined approach and landing operations, four examined taxi operations, two examined unusual attitude recognition and recovery, one examined departure operations, one examined en route operations, and one examined hover maneuvers. Studies were conducted by several organizations. Based on the affiliation of the article's first author, seven studies were led by a researcher from NASA, the two rotorcraft studies were conducted by the German Aerospace Center, and the one GA study was conducted by an FAA researcher.

3.2.2 Themes

From this review, several important themes were discerned (Figure 2). For the two rotorcraft-focused studies, the themes were related to helicopter offshore operations, including using an XVS on an HWD (which included EVS and SVS information) to compensate for the lack of visual cues over water surfaces, adverse visual motion over water surfaces, methods to model the synthetic ocean surface, and the effect of different 3D perspective views. For the eight fixed-wing studies, the themes were related SVS display type (HUD, HWD, HDD); symbology design (size, color, pathway guidance symbology); HWD ergonomics (weight, balance, comfort); ocular design; ambient vision that provided an unlimited FOV; SVS image quality (resolution, brightness, contrast, clutter, occlusion, latency); effects of color (monochrome and colorized); and comparison to traditional sources of information (paper charts, two-dimensional [2D] track-up moving map electronic flight bag [EFB], existing flight deck displays). Scenarios were included to evaluate the effectiveness of an SVS on an HWD to prevent controlled flight into terrain (CFIT) accidents, taxi incursions, unusual attitude recognition and recovery, and during approaches to closely spaced parallel runways.

Figure 2

Graphic Representation of Key Themes Identified in the Research Literature on Synthetic Vision Systems Implemented on a Head-worn Display



3.2.3 Snapshot Reviews of Research Articles on Synthetic Vision Systems Implemented on a Head-worn Display

Snapshot reviews of the 10 research articles that met the inclusion criteria are provided in Table 2. The intent of these reviews is to provide information of sufficient detail to give a sense of the nature of the research and to help stakeholders identify references for key themes.

Table 2

Article Summaries for Research on Synthetic Vision Systems Implemented on a Head-worn Display

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
Arthur et al. (2004).	• SVS on an HWD: full color, monocular (left eye) • SVS on an HDD • SVS on an HUD	• Airplane • Approach and landing • HDD • HUD • HWD • Pathway guidance symbology • Ergonomics • Monocular optics • CFIT	**Participants:** Eight airline or aircraft manufacturer pilots **Apparatus:** Transport category aircraft part-task simulator or a Boeing 757 research simulator; three display concepts: (1) SVS on an HDD; (2) SVS on an HUD; and (3) SVS on an HWD **Procedure:** Participants flew a visual circling maneuver during Instrument Meteorological Conditions (IMC) at a terrain-challenged airport. All approaches started from an offset position to evaluate pathway guidance symbology.	Display type (SVS on a HDD, HUD, or HWD) had no effect on vertical or lateral navigation path performance. Subjective workload was rated higher for the SVS on an HWD, and lower for the SVS on a HUD or HDD. Subjective situation awareness was rated as higher for the SVS on an HDD and HUD, and lower for the SVS on an HWD. Participants ranked their preferred display type as: (1) SVS on an HUD; (2) SVS on an HDD; and (3) SVS on an HWD.
Arthur et al. (2006).	• SVS on an HWD: full color, monocular (right eye) • 3D SVS EFB Display	• Airplane • Taxi • Approach and landing • Departures • Paper charts • EFB • HWD • Position awareness	**Participants:** Eight pilots, including six commercial and two test pilots **Apparatus:** Part-task simulator modeled on a Boeing 757; four display or information concepts: (1) SVS on an HWD; (2) 2D moving map EFB;	For experiment 1, task performance and situation awareness were higher for taxi operations conducted with the SVS on an HWD compared to the 2D EFB or paper charts.

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
		• Terrain awareness • CFIT	(3) 3D SVS EFB; and (4) paper charts **Procedure:** Participants evaluated an SVS on an HWD, 2D track-up moving map EFB, and a paper chart during simulated taxi under unlimited and Category II (CAT II) visibility conditions. In a second experiment, participants evaluated a 3D SVS EFB during approaches and departures in an operationally-challenged airport environment.	For experiment 2, subjective ratings for terrain awareness, position awareness, and path awareness were higher for the 3D SVS EFB than e-paper or paper charts during approach and departure operations.
Arthur et al. (2007).[3]	• SVS on an HWD: full color, monocular (right eye) • SVS on an HWD: full color, monocular (right eye), advanced taxi route clearance, taxi precision guidance, and data-link capability	• Airplane • Taxi • Paper charts • EFBs • Airplane • HUD • HWD • Symbology size and color • Taxi incursions	**Participants:** Sixteen commercial flight crews **Apparatus:** Part-task simulator modeled on a Boeing 757; six display concepts (1) paper charts with existing flight deck displays; (2) baseline consisting of existing flight deck displays including a Class III EFB display of the airport surface; (3) an advanced baseline that also included displayed traffic and routing information; (4) a modified version of a HUD and electronic moving map (EMM) display demonstrated in previous research; (5) an unlimited field of regard (FOR), full color, head-tracked HWD with	Navigation performance was best for the advanced HUD concept, followed by the advanced HWD concept. In contrast, taxi incursions were more likely with the advanced HUD concept, and least likely with the advanced HWD concept. This suggests the HUD concept may be associated with increased risk for cognitive capture. Some crews missed a nose-to-nose taxi incursion event, likely due to the traffic symbology size and color. Once the symbology was modified, no crews

[3] Arthur et al. (2009) and Arthur et al. (2007) discuss the same research; to maintain brevity, this review excludes Arthur et al. (2009).

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
			a conformal 3D SVS; and (6) a fully integrated HWD concept with advanced taxi route and traffic. **Procedure:** Participants evaluated six display concepts during taxi under conditions ranging from unlimited visibility at night to RVR 500 ft during the day.	got into a nose-to-nose situation. There were no workload differences across displays. Subjective situation awareness was rated higher for the advanced display concepts.
Arthur et al. (2008).	• SVS on an HWD: full color, monocular (right eye)	• Airplane • Taxi • HUD • HWD • Latency • Ergonomics • Image quality • HWD operating complexity	**Participants:** Eight pilots, including six commercial pilots and two test pilots **Apparatus:** Part-task simulator modeled on a medium- to long-haul commercial passenger aircraft; two HWD concepts, with each having both single-mode and multi-mode. Single-mode consisted of a 2D EMM, plan view display; multi-mode allowed the selection of four display concepts: (1) text display of the taxi clearance; (2) a 2D EMM; (3) a zoomed-in 2D EMM for precise surface guidance; and (4) a 3D perspective display. **Procedure:** Participants evaluated two HWDs during simulated taxi operations in visibility conditions that ranged from clear day to RVR 1000 ft.	There were no significant differences between the advanced HUD and advanced HWD display concepts on measures of taxi performance, workload, or situation awareness. Human factors considerations for HWDs included latency for head-tracking systems; HWD weight, balance, and comfort; the effect of transitioning between phases of flight; image issues such as resolution, brightness, contrast, and use of color; alignment and accuracy; and complexity of operating an HWD system.
Arthur et al. (2011).	• CVS HWD: monochrome green, monocular	• Airplane • Approach and landing • Taxi	**Participants:** Nine airline pilots	For the approach task, participants rated situation awareness and

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
	• EVS HDD	• HUD • HWD • Airport environment symbology • Aircraft symbology • Display clutter • Display occlusion • Closely spaced parallel runways	**Apparatus:** Large transport category aircraft simulator; three display concepts: (1) EVS HDD; (2) CVS HWD; and (3) visual. For the HWD, airport and traffic symbology were presented on an EVS image. For the HDD, the participant was able to pan the variable view FOR EVS image left or right. **Procedure:** Participants flew simulated closely spaced parallel approaches with the three display concepts. In a follow-on study, participants completed taxi scenarios, with airport symbology, traffic symbology, and visibility manipulated. Visibility conditions were as low as RVR 300 ft.	mental workload for the CVS HWD as equivalent to visual approaches. For the taxi task, there were no situation awareness or mental workload differences based on display type. Participants preferred a generic aircraft model icon to unfilled diamond icons, because they were easier to interpret and provided heading information. Suggestions were made to use small and large aircraft models to denote small and large aircraft. Participants also commented that the synthetic airport symbology increased their situation awareness and that they preferred having as much information available as possible at low visibilities.
Arthur et al. (2017).	• SVS on an HWD with ambient vision: full color and green symbology, bi-ocular • SVS on an HDD	• Airplane • Unusual attitude recovery • HDD • HUD • HWD • FOV • Ambient vision • Symbology color • Ergonomics • Display latency	**Participants:** Twelve commercial flightcrews **Apparatus:** A research flight deck simulator, without motion cueing, configured with an instrument panel similar to a commercial transport aircraft; three display concepts included: (1) a HUD; (2) a biocular HWD with ambient vision capability; and (3) HDD with and without SV.	Overall, participants were able to recover from all the unusual attitude scenarios for all of the display types, with no operationally significant differences in performance, situation awareness, or workload. However, for the HWD, further consideration is needed for the effects of symbology color, ergonomics, and display latency, as well as the effects of turbulence during

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
			Procedure: Participants flew simulated unusual attitude recovery scenarios with a. For the HWD, the ambient vision displays were toggled on and off to evaluate the effects of an unlimited FOV on attitude awareness, and both color and green symbology were evaluated. The airplane was placed in an unusual attitude, and the participants were asked to recover. Additional scenarios were completed with an operationally realistic non-normal condition used to induce an unusual attitude. These included a radar altimeter failure, a fuel leak, a degraded autopilot, and a wake encounter.	different lighting conditions.
Beringer (2020).	• SVS on an HWD: binocular, full color, and monochrome green wireframe variants • SVS on an HUD: monochrome green • SVS on an HDD: full color	• Airplane • GA • HDD • HUD • HWD • Approach and landing • En route • Missed approach	**Participants:** Study 1: eight instrument-rated GA pilots; Study 2: 12 instrument-rated GA pilots **Apparatus:** A research-configured flight simulator representing a Piper Malibu/Meridian; Study 1 display concepts: (1) SVS on a HUD; and (2) SVS on an HDD; (3) electronic PFD on an HDD; and (4) conventional round-dial instrumentation. Study 2 display concepts: (1) SVS on an HUD; and (2) SVS on an HWD	SVS display type had no effect on ILS tracking performance, based on results from study one. For the second study, there were some differences in ILS tracking performance, but the participants were able to complete the approach and landing with each display type. The touchdown point past the touchdown zone was, on average, 323.5 ft for the SVS on an HWD, and 221.5 ft for the SVS on an HUD. The mean difference from

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
			Procedure: Study 1: Participants flew approach procedures at RVR 1200 ft or RVR 1400 ft with an SVS on a HUD, SVS on an HDD, an electronic PFD on an HDD, or a conventional HDD with round-dial instrumentation. Study 2: Participants flew two approaches at RVR 1200 ft or RVR 1400 ft with a SVS on a HUD or SVS on an HWD. One approach was with ILS guidance, and the other was with Localizer guidance.	the centerline was 4.5 ft for the SVS on an HWD and 2.6 ft for the SVS on an HUD. Focusing on the SVS on an HWD, pilots preferred the monochrome green wireframe over the colored texture display.
Ernst et al. (2018).	• XVS (including EVS and SVS information) HWD: non-see-through "virtual reality goggles"; fused sensor and database information	• Helicopter • Virtual reality goggles • Approach • Helicopter offshore operations • Lack of visual cues over water surfaces • Adverse visual motion over water surfaces • Synthetic ocean surface representations	**Participants:** Nine helicopter pilots **Apparatus:** Fixed-base, multi-purpose flight simulator; four HWD concepts to represent ocean surfaces: (1) natural; (2) flat-round; (3) flat-peak; and (4) elevated. The natural representation included waves, water reflections, and refractions. The elevated was a uniform, wave-like 3D mesh with a grid structure oriented with the wind direction. The flat-round and flat-peak were simple flat structures with grid surfaces. These display types represented different wind strengths, wind directions, and wave conditions. **Procedure:** Participants flew maneuvers in a helicopter simulator	The natural ocean-surface representation was associated with the least accurate wind direction assessments. All display types were associated with excessively high deviations from the desired ground speed. Participant ratings for the degree of support for estimating wind directions and speed, and performance of the flight task were lowest for the natural ocean surface representation, and highest for flat-round and elevated models. Overall, participants preferred the elevated model. Pilots largely agreed that displaying wind direction and speed with grid symbology is useful, and that the grid also helps to assess drift.

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
			without flight instruments and were asked to judge the wind direction based on the water representation, turn the helicopter into the wind, adjust airspeed, and conduct a straight approach with constant deceleration and descent.	Arrows used to indicate wind direction were also deemed helpful.
Ernst et al. (2019).[4]	• XVS (including EVS and SVS information) HWD: non-see-through "virtual reality goggles"; fused sensor and database information	• Helicopter • Hover • Virtual reality goggles • Helicopter offshore operations • Lack of visual cues over water surfaces • Adverse visual motion over water surfaces • Synthetic ocean surface representations • Restricted external view • 3D egocentric view • 3D exocentric view • Spatial awareness	**Participants:** Eight helicopter pilots **Apparatus:** XRSim four HWD concepts to represent four 3D perspective views: (1) cockpit-base; (2) cockpit-trans; (3) exocentric-base; and (4) exocentric-trans. Cockpit-base replicated a conventional cockpit and served as the baseline condition. Cockpit-trans creates an unblocked view by making the helicopter fuselage transparent. Exocentric-base and exocentric-trans provided a view from behind and above the helicopter. **Procedure:** Participants flew scenarios that required hovering close to a wind turbine tower using four HWD 3D perspective views; all maneuvers were flown without flight instruments.	Participants could find and hold a hover point more precisely with the exocentric perspective views compared to cockpit views. Further, participants could see the helicopter, the obstacle, and the virtual primary flight display at the same time, requiring fewer head movements. Participants reported improved spatial and obstacle awareness with the exocentric views. However, attitude control performance was best with the Cockpit-Base view, likely because of the additional visual cues provided by the conventional cockpit. When sitting inside the cockpit, the horizon moves within the participant's FOV. With exocentric views, the horizon was always horizontal and did not move vertically within the participant's

[4] This paper included results from Ernst et al., 2018, and an additional study on egocentric and exocentric perspective views. Results from the second (new) study are provided here.

Author	Synthetic Vision System and Display	Key Themes	Methodology Overview	Outcome, Results
				FOV when they altered pitch or roll angle.
Nicholas et al. (2019).	• SVS on an HWD: binocular, monochrome • SVS on an HWD: binocular with ambient vision (transparent), monochrome • SVS on an HWD: binocular with ambient vision (opaque), monochrome	• Airplane • Approach and landing • Takeoff • Unusual attitude prevention • HDD • HUD • HWD • Ambient vision • Attitude recognition • Attitude alerting • Startle/surprise • Ergonomics • Spatial disorientation • Loss-of-control in-flight	**Participants:** Twenty-four airline pilots **Apparatus:** A development and test simulator modeled on a Boeing 757; four HWD display concepts: (1) baseline HDD; (2) SVS on an HWD; (3) SVS on an HWD with ambient vision (transparent); and (4) SVS on an HWD with ambient vision (i.e., opaque). **Procedure:** Participants flew takeoff, approach, and landing scenarios using four display concepts. Scenarios were intended to induce an unusual attitude and included runaway right rudder trim coupled with a right engine flameout to induce a roll upset, windshear to induce a pitch down upset, and a large wake vortex to induce a roll upset.	Participants took longer to recover from a windshear-induced pitch upset with the baseline HDD, requiring approximately 4.8s longer to recover compared to other displays. Participants rated their situation awareness as higher when using an HWD with ambient vision (opaque or transparent) compared to other displays. Many participants reported that the particular HWD used in the study was uncomfortable, heavy, bulky, and caused pressure on the nose and eye strain, suggesting that HWD ergonomics is an important factor.

3.3 Discussion

This literature review highlights the predominant themes identified in the 10 research articles on SVSs implemented on HWDs and sheds light on some important design criteria and associated operational implications. One central theme was related to HWD ergonomics. Factors such as HWD weight, size, balance, and comfort can have implications on its safe and effective use. Several studies noted concerns with participant comfort, such as reports of pressure points, hot spots, and eye strain (Arthur et al., 2004; Arthur et al., 2008; Arthur et al., 2017; Nicholas et al., 2019). However, it is important to note that the HWDs used in these studies were customized hardware devices developed for research, which may not be representative of the HWDs that are now commercially available to the civil aviation market. Regardless, ergonomic design is important for any wearable device that is in constant contact with the end user. Design of wearable devices should minimize the likelihood of user discomfort, injury, or cognitive distraction. A modern flight deck is a demanding workplace, and pilots are tasked with completing multiple activities simultaneously, such as extracting information from a variety of sources, forming a mental model of the flight situation, completing tasks in a sequenced order, and coordinating activities with other flightcrew members and with entities outside of the aircraft. The consequences of interruptions and distractions, such as those that may occur when wearing an uncomfortable or ill-fitting piece of equipment, can range from a minor inconvenience to a more serious safety event. Examples of possible consequences of distractions or interruptions include reordering of sequenced activities, deferring planned actions, forgetting to execute actions in the future, or disruptions to crew coordination. Distractions when operating close to the ground, such as during approach and landing, may increase the likelihood of poor performance on flightpath and energy management tasks, which may in turn increase the likelihood of an unstabilized approach, CFIT accident, failing to detect problems (e.g., alerts, intruder traffic), or runway excursion. A distraction during the cruise phase of flight could affect how pilots monitor displays, which could increase the likelihood of failing to detect abnormal system parameters or settings.

The second central theme is related to SVS symbology and imagery. HWD symbology should present the most pertinent information in a usable and intuitive form while minimizing distractions that could impact performance. Pilots are trained to visually scan flight instruments in a specific manner, and the location and format of the information should be designed in such a way that the pilot can quickly assimilate information into their mental model of the flight situation. In the research examined here, traffic symbology size and color influenced the participants' ability to detect taxi incursion events (Arthur et al., 2007). Symbology brightness, contrast, intuitiveness, and image resolution were also identified as important design factors (Arthur et al., 2004; Arthur et al., 2007; Arthur et al., 2011; Arthur et al., 2017). For example, participants preferred an aircraft traffic icon that allowed them to interpret heading information, as well as large icons to represent large aircraft and small icons for small aircraft. For ground operations, participants commented that synthetic airport symbology increased their situation awareness, especially in low-visibility conditions. The two rotorcraft studies were task-specific to offshore operations, such as hovering near a wind turbine or approaching an offshore platform (Ernst et al., 2018; 2019). For these scenarios, an XVS HWD appeared to offer a promising solution for counteracting hazards related to the lack of visual cues over an ocean surface and modeling wind and motion cues on an ocean surface. In sum, thoughtful design of the HWD symbology and imagery appeared to provide operational benefits, but simply adding more information to a display does not necessarily lead to a clear improvement in safety or performance. Symbology should be intuitive and meaningful, while considering the effects on distraction and pilot visual scanning behavior.

A third theme focused on SVS display type, such as comparing SVSs implemented on a HUD, HDD, and HWD. In general, display type did not have an operationally significant effect on any of the flight performance metrics examined. For example, when flying a circling maneuver in a terrain-challenged environment, there were no significant differences in vertical or lateral navigation path performance between SVS on a HUD, SVS on an HWD, or SVS on a HDD (Arthur et al., 2004). In another study, pilot participants were able to recover from unusual attitude scenarios using an SVS on an HDD and an SVS on an HWD (Arthur et al., 2017). In a third study, during which pilots used SVS on an HDD, SVS on an HUD, and SVS on an HWD during SA CAT I approaches, there were no operationally significant performance differences based on SVS display type (Beringer, 2020). It is important to note that while display location or type did not appear to influence flight performance metrics, other piloting tasks that were not examined may still be affected. For example, Ververs and Wickens (1998) demonstrated that flight performance was equivalent for tasks completed using an HUD or HDD; however, performance for detecting commanded changes and traffic was better in the HUD condition. This may be because the HUD required fewer changes to visual scanning requirements, compared to a HDD. Similarly, results from ground transportation research indicated that more consistent speed control and shorter response times to urgent events were achieved when using an HUD, compared to an HDD (Liu & Wen, 2004).

A fourth theme focused on assessing how the source of information used by pilots on the flight deck impacts their performance. This is an important consideration, as changes in format or presentation of information can influence the amount, complexity, and efficiency of information processing that the pilot is required to perform. Several of the studies reviewed in this report compared SVS on an HWD to other sources of information, such as a 2D track-up moving map EFB, paper charts, HUDs, and existing flight deck displays (Arthur et al., 2006; Arthur et al., 2007; Arthur et al., 2008; Nicholas, 2019). In some cases, there were no significant performance differences based on the source of information, and other times, there was an operational benefit for the electronic display. Electronic displays have the benefit of being able to integrate multiple sources of information in one location, potentially reducing workload and supporting situation awareness.

In sum, the research about SVS implemented on an HWD has demonstrated that thoughtful consideration of display ergonomics, symbology design, and imagery design have important implications for any operational or safety benefit to the device. Further, SVSs implemented on HWDs have the potential to support the pilot or flight crew during several phases of flight. However, important aspects of HWDs were not directly studied in the 10 articles included in this review. Examples include the effect of display type on different piloting tasks, such as evaluating pilot reactions and responses to flightdeck alerts or malfunctions, the effect of the display on risky decision-making, or the effect of the display on pilot visual attention or scanning behavior. Additionally, the effects of eye dominance, ocular display (i.e., monocular, bi-ocular, binocular), and the use of a monocular HWD with both the participants' dominant and non-dominant eyes require further evaluation.[5] Different environmental conditions, such as changes in ambient lighting, operations in environments with substantial ground lighting (e.g., "sea of lights" in metropolitan areas), different forms of obscuration, or using an HWD in turbulence, should also be considered.

[5] Approximately 65% of the population are right-eye dominant, 32% are left-eye dominant, and 3% show no consistent preference (Porac & Coren, 1976).

4.0 Survey of Expert Opinion on Human Factors and Operational Considerations for Synthetic Vision System Head-worn Displays

The purpose of this research was to survey expert opinion on industry interest, as well as human factors and operational considerations of SVSs implemented on an HWD. Ultimately, the results of this survey may help inform future research direction to keep pace with technological advancements and industry demands. Advances in the development of SVSs, HWDs, and associated certification, evaluation, and operational activities, suggest that the number of individuals with direct hands-on experience with SVSs and HWDs is larger now than in previous years. Because of this, we intentionally sought to recruit and survey individuals who had personal experience with these technologies to obtain their insights.

4.1 Method

The questionnaire content was developed through an extensive review of related literature and through collaboration with FAA stakeholders and SVS and HWD subject matter experts. The questionnaire was designed using Qualtrics© Survey Software for electronic distribution and online completion. The questionnaire consisted of 57 items with a filter item used to route respondents to items relevant to them based on their employment, such as an avionics OEM, aircraft OEM, or an aircraft operator or air carrier. The questionnaire was organized into three sections: generic questions relevant to all respondents, additional questions for avionics OEM respondents, and additional questions for aircraft operator or air carrier respondents. The questionnaire was comprised of multiple-choice questions, along with open-ended text boxes for respondents to use for explanations or additional comments about their responses (e.g., “please explain”). A pilot test of the self-administered questionnaire suggested that it could be completed in approximately 30 minutes.

The questionnaire was distributed via an email containing a generic hyperlink to complete the survey. The invitation email was sent to industry contacts who were asked to complete the questionnaire and to further share the invitation with other industry professionals with experiences relevant to SVSs and HWDs. Participation in this research was voluntary and anonymous, and respondents were not paid. The FAA Civil Aerospace Medical Institute (CAMI) Institutional Review Board reviewed and approved the research study (Approval No. 202418). No identifying information was collected, and responses were downloaded onto servers maintained by the FAA. Responses to open-ended items or comments were thoroughly reviewed to ensure that respondents did not disclose personally identifiable information.

The survey was available from August 20 to September 17, 2024. A total of 66 respondents completed the full questionnaire, and another 46 completed some portion of the questionnaire. For partial responses to be included in the analysis, they had to meet the inclusion criteria established for (a) questionnaire completion rate and (b) familiarity with SVSs or HWDs. Respondents who completed at least 70% of the survey were retained. To ensure that the inclusion rule did not unnecessarily exclude the target population (avionics OEMs, aircraft OEMs, and operators with SVS or HWD experience), researchers reviewed the partial responses and retained one participant with less than 70% completion. This process resulted in 80 respondents retained in the dataset. The dataset was refined to include only those respondents who reported being moderately, very, or extremely familiar with either SVSs or HWDs. This refinement reduced the dataset to 61 respondents. Finally, nine respondents who reported employment at an avionics OEM but did not respond to questions related to familiarity with SVSs or HWDs were also retained, resulting in a final dataset of 70 respondents retained for analysis.

4.2 Participants

For this paper, an *Expert* was defined as those respondents who reported being moderately familiar, very familiar, or extremely familiar with SVSs (n = 60) or with aviation HWDs used on an aircraft during flight (n = 51). As respondents could be familiar with one or both systems, the criteria for being considered an Expert were based on having at least moderate familiarity with either system. Overall, 61 respondents met the criteria for SVS or HWD Experts, with approximately 82% of respondents meeting the Expert criteria for *both* SVSs and HWDs. Of the 60 SVS Experts, 10 were not HWD experts. Of the 51 HWD Experts, one was not an expert in SVSs. Upon review of the survey results, there appeared to be no systematic difference in patterns of responding between those who reported moderate or greater familiarity with only one technology and those who reported moderate or greater familiarity with both technologies. Therefore, for the sake of brevity, responses were combined to form one Expert group. The nine additional respondents employed by avionics OEMs who did not respond to questions about familiarity with SVSs or HWDs were also retained for analysis and included in the Expert group.

Of the 70 respondents, 31.4% (n = 22) worked for a government agency. It should be noted that although this was an anonymous survey, representatives from four civil aviation authorities and U.S. federal government agencies outside of the FAA were invited to participate. Additionally, 25.7% (n = 18) of respondents worked for a company that designs, manufactures, supplies, or services avionics systems; 25.7% (n = 18) worked for a company that designs and manufactures aircraft; 12.9% (n = 9) worked for an aircraft operator or air carrier; 2.9% (n = 2) identified as an aviation vision system subject matter expert consultant or worked for a software company that designs and develops electronic flight bag software; and 1.4% (n = 1) reported that they were a pilot but did not work in the aviation industry. A distribution of respondents' industry of employment is provided in Table 3, and open-ended text responses with additional information for those who selected "other" are provided in Table 4.

Table 3
Industry of Employment

Industry of Employment	Count (n)	Percent (%)
I work for a government agency	22	31.4
I work for a company that designs, manufactures, supplies, or services avionics systems	18	25.7
I work for a company that designs and manufactures aircraft	18	25.7
I work for an aircraft operator or air carrier	9	12.9
Other	2	2.9
I am a pilot but do not work in the aviation industry	1	1.4
Total	70	100

Note. *N* = 70. Respondents were asked to select one response.

Table 4
Open-ended Text Responses to the Question Prompt, What is Your Work Industry, Please Specify 'Other' Response

What is your work industry, please specify 'Other' Response
Advanced vision consultant
I work for a software company that designs and develops electronic flight bag software.

Of the 70 respondents deemed Experts with SVSs or HWDs, 47 (67.1%) hold one or more pilot certificates: 37 Airline Transport Pilots (ATPs), 25 Commercial Pilots, 20 Certified Flight Instructors (i.e., CFI, CFII, MEI), 12 Private Pilots, six certificated Remote Pilots, and one Student Pilot. The Expert respondents also hold a variety of ratings: 31 Multi-Engine, 29 Instrument Rated, and 31 hold a Type Rating (Table 5 and Table 6). Forty-five Experts reported fixed-wing airplanes as their primary aircraft flown, and one reported rotorcraft as their primary aircraft flown.

Table 5
Pilot Certification and Rating Held

Certificate or Rating	Count (n)	Percent (%)
Airline Transport Pilot	37	52.9
Multi-engine Rating	31	44.3
Type Rating	31	44.3
Instrument Rating	29	41.4

Certificate or Rating	Count (n)	Percent (%)
Commercial Pilot	25	35.7
Certificate Flight Instructor (i.e., CFI, CFII, MEI)	20	28.6
Private Pilot	12	17.1
Remote Pilot	6	8.6
Student Pilot	1	1.4

Note. N = 47/70. Respondents were asked to select all that apply.

Table 6

Open-ended Text Responses When Asked, What Type of Pilot Certificate(s) do you Currently Hold, Please Specify 'Other' Response

What type of Pilot Certificate(s) do you currently hold, please specify 'Other' Response
Test Pilot
Gold Seal CFI and Ground Instructor
Glider-CFI
Flight Test Pilot Cat1 Rating Flight Test Instructor Cat1 Rating
Experimental Test Pilot
Airplane Single Engine Sea

As mentioned, the final sample of Experts retained in the dataset for analysis was dependent on their familiarity with SVSs or HWDs. Familiarity with either system was evaluated on a 5-point Likert scale from Not at All to Extremely Familiar. Among Experts, the mean (or average) response for familiarity with SVSs was 3.97 (*SD* = .82; Figure 3) and the mean response for familiarity with HWD was 3.48 (*SD* = 1.07; Figure 4).

Figure 3
Familiarity With Synthetic Vision Systems

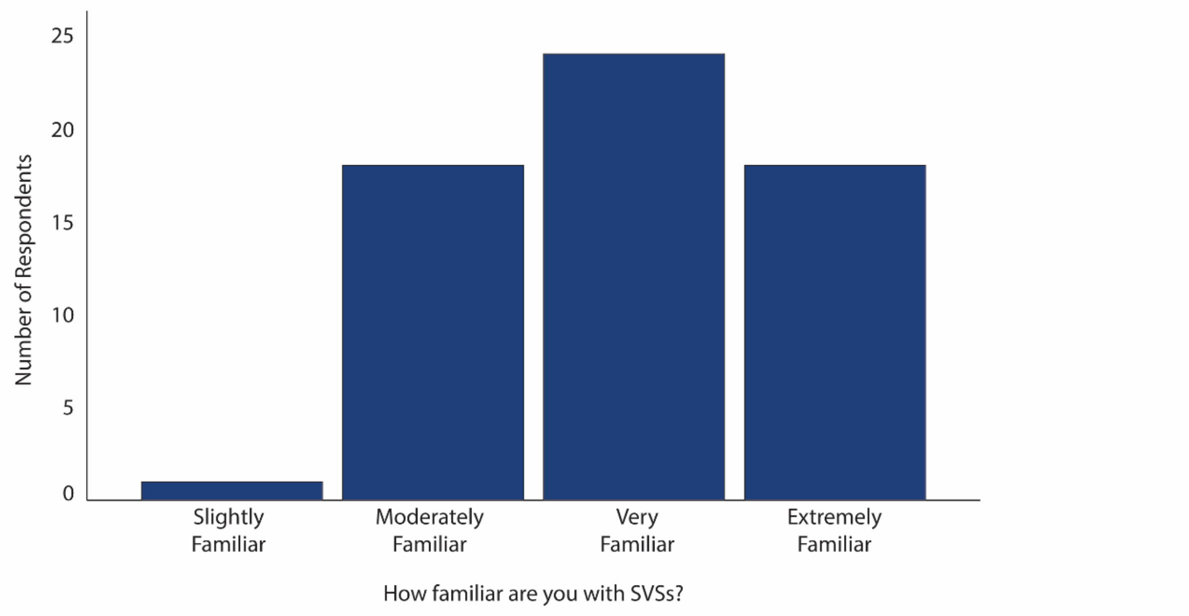
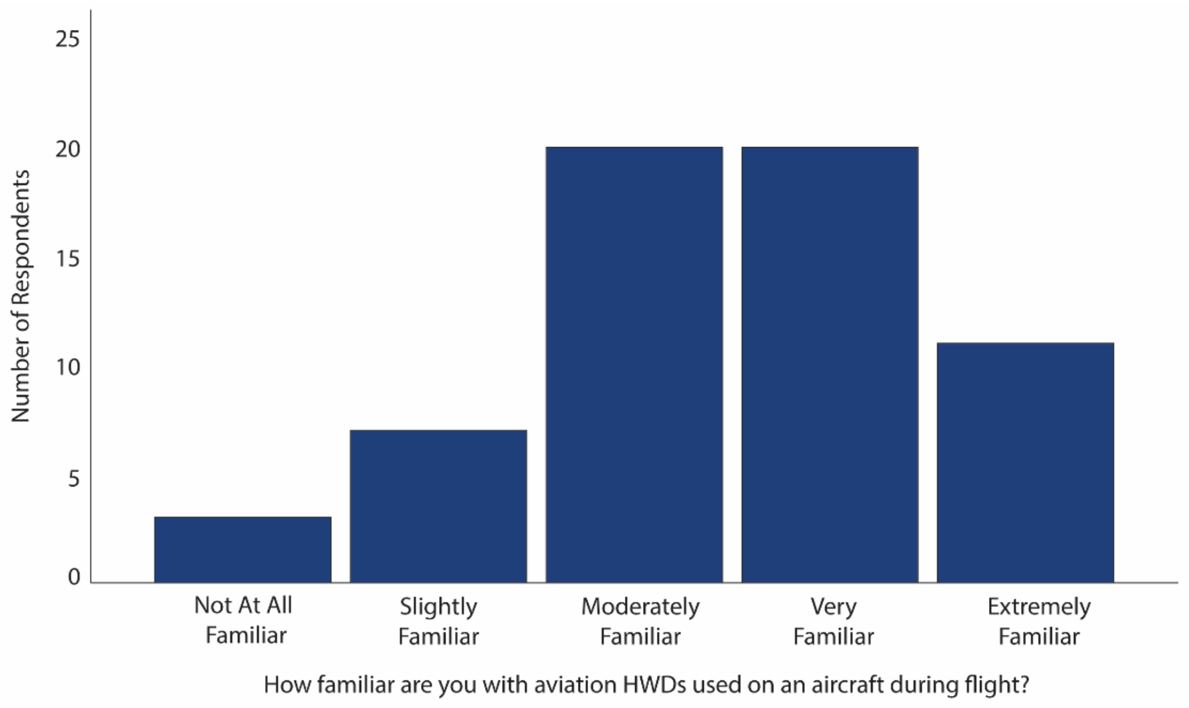


Figure 4
Familiarity With Head-worn Displays



4.3 Results

The following sections provide the results of the survey of 70 SVS or HWD Expert respondents. For the responses to open-ended items, no grammar, spelling, or punctuation corrections were made. Comments are verbatim except for removing any personally identifying information, such as name or contact information, and expletives. Responses are organized by question item and by survey section.

4.3.1 Synthetic Vision System Operational and Safety Benefits

The Expert respondents generally agreed there were operational and safety benefits for SVSs. The 70 Experts were asked what operations would benefit the most from an SVS implemented on an HWD for use during flight. Participants could select multiple responses. Approximately 61.4% (*n* = 43) indicated benefits for Part 91 General Aviation; 60.0% (*n* = 42) indicated a benefit for Part 121 Scheduled Air Carriers; and 57.1% (*n* = 40) indicated a benefit for Part 135 Commuter on Demand Operations. Table 7 provides other types of operations that Experts reported may benefit from an SVS on an HWD.

Table 7

Flight Operations That Would Benefit From a Synthetic Vision System Implemented on an Aviation Head-worn Display for use During Flight

Operation	General Description	Count (n)	Percent (%)
Part 91	General aviation with general flight operating rules	43	61.4
Part 121	Scheduled air carriers with domestic, flag, and supplemental operations, both regional airlines and major airlines	42	60.0
Part 125	Commercial flights by airplanes with the capacity of 20 or more seats and maximum payload capacity of 6,000 pounds or more	37	52.9
Part 129	Foreign air carriers and foreign operators of U.S. registered aircraft engaged in common carriage	30	42.9
Part 133	Rotorcraft external-load operations	31	44.3
Part 135	Commuter and on demand operations, including corporate, government and helicopter operations	40	57.1
Part 141	Flight schools	17	24.3
Part 142	Training centers	22	31.4
Unsure	-	7	10.0
None of the above	-	2	2.9

Note. *N* = 70. Respondents were asked to select all that apply.

When asked what landing minima would be needed to see a safety and/or operational benefit to an SVS implemented on an HWD, the most frequently provided responses were Non-precision Approach and Landings (44.3%; *n* = 31) and SA CAT I with 150ft DH/RVR 1400ft (42.9%; *n* = 30). The next most frequently provided responses were Category I with 200ft

DH/RVR 2400ft (41.4%; n = 29) and Category II with 100ft DH/RVR 1000ft (38.6%; n = 27); see Table 8 and Figure 5 for a full list of operations that the Expert respondents indicated would benefit from an SVS on an HWD. Participants could select multiple responses.

Table 8

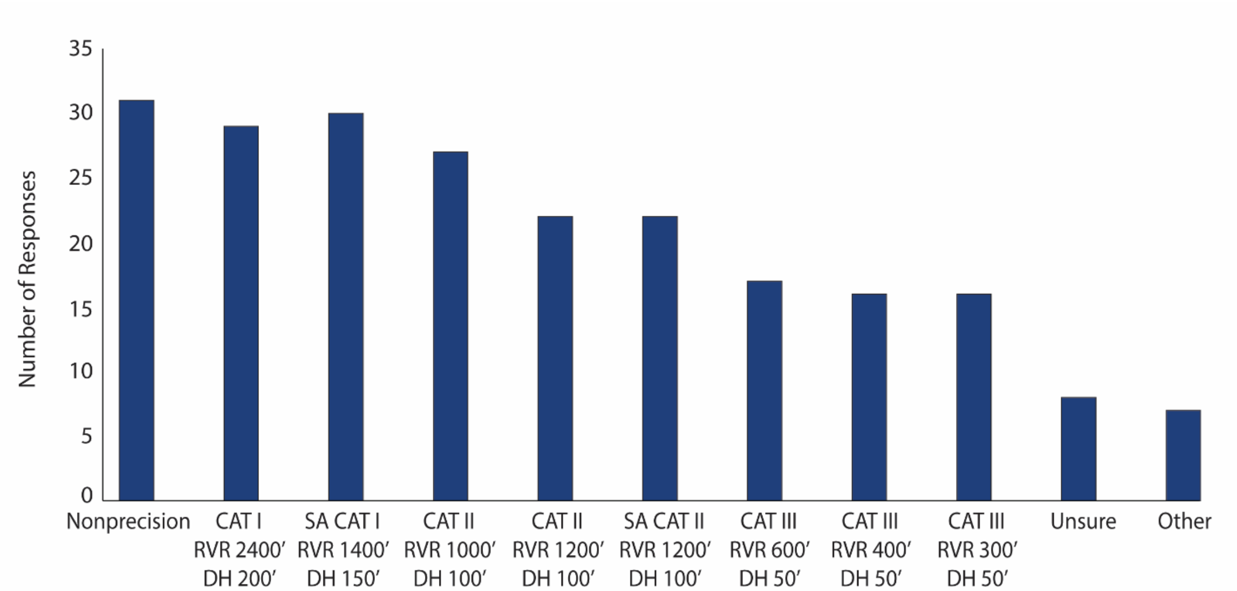
Landing Minima Needed in Order to see a Safety and/or Operational Benefit to a Synthetic Vision System Implemented on an Aviation Head-worn Display

Landing Minima	Count (n)	Percent (%)
Non-precision approach and landing	31	44.3
Category I: 200ft DH/RVR 2400ft	29	41.4
Special Authorization Category I: 150 ft DH/RVR 1400ft	30	42.9
Category II: 100ft DH/RVR 1000ft	27	38.6
Category II: 100ft DH/RVR 1200ft	22	31.4
Special Authorization Category II: 100ft DH/RVR 1200ft	22	31.4
Category III: 50ft DH/RVR 600ft	17	24.3
Category III: 50ft DH/RVR 400ft	16	22.9
Category III: 50ft DH/RVR 300ft	16	22.9
Other	7	10.0
Unsure	8	11.4

Note. N = 70. Respondents were asked to select all that apply.

Figure 5

What Landing Minima Would Be Needed in Order to see a Safety and/or Operational Benefit to a Synthetic Vision System Implemented on a Head-worn Display



Note. *N* = 70. Respondents were asked to select all that apply.

It was also important to consider which phases of flight would benefit the most from an SVS. The most common responses were Landing (77.1%; *n* = 54), Missed Approach (74.3%; *n* = 54), and Takeoff (71.4%; *n* = 50). The number of Expert respondents who indicated other phases of flight is provided in Table 9.

Table 9

Phases of Flight That Would Benefit From a Synthetic Vision System

Flight Phase	Count (n)	Percent (%)
Landing	54	77.1
Missed Approach	52	74.3
Takeoff	50	71.4
Balked Landing (Rejected)	48	68.6
Rollout	44	62.9
Taxi	43	61.4
Descent	43	61.4
Climb	35	50.0

Flight Phase	Count (n)	Percent (%)
Cruise	16	22.9
Unsure	2	2.9

Note. *N* = 70. Respondents were asked to select all that apply.

As an additional follow-up question, Experts were asked to consider which type of displays would be the most beneficial during each phase of flight; the leading response was HUD, followed by an HWD (Table 10).

Table 10

Most Beneficial Display Type for Each Flight Phase

	Respondents (n)						
Flight Phase	HDD (n)	HDD (%)	HUD (n)	HUD (%)	HWD (n)	HWD (%)	Total (n)
Landing	3	5.6	34	63.0	17	31.5	54
Missed Approach	4	7.8	27	52.9	20	39.2	51
Takeoff	5	10.0	33	66.0	12	24.0	50
Balked Landing	3	6.3	24	50.0	21	43.8	48
Rollout	3	6.8	21	47.7	20	45.5	44
Taxi	8	18.6	11	25.6	24	55.8	43
Descent	6	14.0	21	48.8	16	37.2	43
Climb	7	20.0	13	37.1	15	42.9	35
Cruise	8	50.0	5	31.3	3	18.8	16
Total	47	12.2	189	49.2	148	38.5	384

Note. *N* = 70. Respondents were asked to select one response for each phase of flight.

Expert respondents provided responses to an open-ended question on the safety and operational benefits of SVSs. The common response themes were that SVSs enhance pilot situation awareness, that all phases of flight could benefit from the use of an SVS, and that an SVS has the potential to reduce landing minima. Expert respondents thought that SVSs would support identification and awareness of divert airports, obstacles (especially if they are not "see-able" with a forward-looking infrared [IR] image), terrain, obstructions, and traffic, and would reduce the likelihood of CFIT. They also thought that SVSs help to validate the aircraft's position and support pilot detection of inaccurate guidance from a localizer or GPS. Display clutter was an identified concern (Table 11).

Table 11

Open-ended Text Responses When Asked, What are Some Safety and/or Operational Benefits of a Synthetic Vision System

What are some safety and/or operational benefits of a synthetic vision system?
• Validation of the airplane's position. • This depends on the SVS. What are its capabilities? Granularity of the SV data; inclusion of and reliability of the obstacle data if presented, GPS accuracy, etc. We have seen erroneous GPS positions effect SV presentation, however, this was in the early days of WAAS[6]. • They provide excellent situational awareness for things such as divert airfields and possible terrain/obstructions. I see SVS as being more useful in the enroute phase of flight than the approach and landing phase of flight. • Synthetic vision systems can contain three-dimensional representations of traffic, terrain, obstacles, runways, taxiways, and other objects critical to understand in relation to the current trajectory of the aircraft. • Synthetic vision system assists both pilots with maintaining situational awareness of terrain, runway extended centerline, runway and obstacles in proximity to flight path. • Synthetic representation of the airport location and runway center-line improves awareness, any other synthetic representation such as obstacles and terrain adds clutter and is unsafe. Enhanced vision, on the other hand, adds safety because it is actual perceived terrain and obstacles, not a data-based static representation that is synthetic. • SVS provides additional SA for terrain and obstacles. Also, SVS symbology like extended airport centerline, airport outline or airport flag is huge addition to SA. • SVS comes in various quality (from poor depiction/resolution of terrain to excellent). The high quality designs increase situational awareness and reduces CFIT (Controlled Flight Into Terrain) amongst other benifits depending on your phases of flight. • SVS - situational awareness. If Navigation sources were reliable enough, could be used to help with low visibility situations. EVS - Low visibility landings, cloud (Thunderstorm) avoidance at night. • Spatial and situational awareness of aircraft relative to terrain, airport, runway, obstacles and other aircraft. • Situational awareness, especially in weather or at night. • Situational awareness primarily. Although advances in SVS could provide additional benefits. • Situational awareness and opportunity to provide additional symbology and information to the flight crew such as runway and taxi thresholds, runway remaining, possible other traffic, etc. HWD provides better situational awareness than a head-down display but all displays provide safety/operational benefits. • Situational awareness • Significantly improved situational awareness, supplementary and complementary information and function or the intended use case, improved safety case

[6] Wide Area Augmentation System (WAAS) is an extremely accurate navigation system developed for civil aviation.

What are some safety and/or operational benefits of a synthetic vision system?
• See CAST ASA report[7]. • Safety: obstacles that aren't "see-able" with a FLIR sensor. Operational: need rule making to allow credit below CAT 1 • Relieves PF/PM from having to visualize the aircraft positional state making analog/digital information apply able. • Reduced mins, reduced lighting requirements, increased SA for PM • Real outside view of terrain and runways when outside view is obscured • Provides additional context and diverse cues to ensure the Pilot can scene-match and confirm visual cues and more quickly reject false cues. • Provide situational awareness along the flight path trajectory. • Provide a consistent and continuous, independent from weather conditions, source of terrain information and the position of the aircraft in relations to the surrounding. • Potentially extended instrument segment (i.e. lower minima) and an easier transition from instrument to visual segment. • Obstacle and terrain awareness • Much better assessment of the surroundings under low visibility such as night or bad weather situation, up to the final approach under 200ft • more awareness and reducing the minima for some approaches. • lower the procedures minima; increasing safety throughout several types of operations due to increased situational awareness; more robustness on landing/go around decisions; overall improvement on all LO VIS operations (ground and air). • It's mainly a safety advantage, due to the increased awareness of the environment: orography and obstacles are presented in conformal view along the approach path, as well as the runway perimeter, threshold location, nearby interections with taxiways, corssing runways etc. Therefore the advantage is not only when airborne, but also when going around and eventually wehn landing and taxiing: all LVO activities would benefit from SVS presented on HMD (or HUD) • It can potentially increase situational awareness of topography in lower light situations if implemented correctly. • Increased situational awareness • Increased Situation Awareness of their environment in terminal areas and visualization of their flight path and potential location of traffic. • Increased situation awareness and reduced landing minima, while maintaining heads up. • Increased SA. Terrain avoidance. • increased CRM, lower risk to mission and cres • Increase situational awareness Achieve more precise approach Improve transition to visual cues for land • Improved situational awareness, reduced CFIT. Possibility for reduced minima for Cat I or non precision approaches when combined with EVS for a CVS solution.

[7] Commercial Aviation Safety Team, (2014). Airplane State Awareness Joint Safety Analysis Team: Final Report Analysis and Results. https://www.cast-safety.org/pdf/JSAT-ASA_FinalReport_June2014.pdf

What are some safety and/or operational benefits of a synthetic vision system?
• Improved flight crew awareness of terrain, geographical features, and expected obstacles (e.g., wires) around the runway environment and along the flightpath. SVS may also improve the flight crew's ability to detect inaccuracies in the ILS or GPS-based flight guidance (e.g., localizer bend). SVS may also reduce crew workload during critical points of flight operations (e.g., at the DA/DH). These could all result in operational benefits, such as new low-visibility operational authorizations when SVS is in use. In turn, this could improve the operational tempo of the NAS and reduce the number of flight delays and cancellations. • Improved awareness particularly in low visibility conditions • I am not very familiar with synthetic vision beyond reading articles. • Helps with avoiding and recovery from unusual attitudes, recognition of unplanned descent, and low visibility operations. • Greater Situational Awareness. Drastically improved terrain/obstacle awareness, particularly at night or extreme visual conditions in mountainous areas or cities. • enhancing safety on remote strips with poor facilities (no/reduced approach lighting system, runway lighting, markings), poor contrast (snowy or arid environment). Operationally reducing the occurrences of diversions by operating with lower minima (especially if Non precision only/visual approaches) • Enhanced situational awareness. Better decision making. Enhanced safety for obstacle avoidance. CFIT mitigation. • Enhanced situational awareness and improved proficiency with visual systems. The HGS is not used by all Pilots in all situations. • Enhanced situation awareness and maybe the elimination of spatial disorientation. • Depending on what is integrated into the specific SVS, this is awareness of terrain, other aircraft, surface vehicles, obstacles, runway/ taxiway, especially in degraded visual conditions. • Crew awareness, situations awareness. • Checking instrument cues vs. data base driven scene. Not as important on RNAV type approaches since both are data base driven. • Better visualization of manmade structures. TAWS Terrain feature typically only shows terrain but the database knows the manmade structures for GPWS but does not display them. • Better situational awareness of terrain. • Better SA and confirmation of NAV and runway information • Again, two different things. From a safety standpoint, having better awareness of terrain features is better. Having the lubber line in a synthetic system allows better SA for final approach. • Added situational awareness

Note. Crew Resource Management (CRM); Area Navigation (RNAV)

When asked whether any safety and/or operational benefits of an SVS were dependent on the display type (i.e., HDD, HUD, HWD), 59 Experts responded to the question. Of those Experts, 89.8% (*n* = 53) indicated “Yes”, safety benefits are display-dependent. Of those 53 respondents, 73.6% (*n* = 39) indicated HUDs would be most beneficial, 58.5% (*n* = 31) for HWDs, and 43.4% (*n* = 23) for HDDs (Table 12). Participants could select multiple responses.

Table 12

Safety and/or Operational Benefits of a Synthetic Vision System: Most Beneficial Display Type

Display	Count (n)	Percent (%)
Head-up Display (HUD)	39	73.6%
Head-worn Display (HWD)	31	58.4%
Head-down Display (HDD)	23	43.4%

Note. *N* = 53. Respondents were able to select multiple responses.

4.3.2 Synthetic Vision System Limitations

When Expert respondents were asked “what do you think most impacts the benefit of a synthetic vision system?”, examples of common responses included accuracy of the terrain and obstacle database information, method of conveying inaccurate or unreliable SVS performance, and potential vulnerability to GPS jamming or spoofing (Table 13). One Expert respondent noted that rotorcraft operations may be especially vulnerable to inaccurate or outdated terrain database information. Display clutter and imagery colorization were also concerns, as noted by one Expert respondent, “Obstacles and terrain in a head up display add clutter and confusion (fly along a shoreline to see blue sky, and blue water with the shoreline seeming to be a banked horizon line. Fly inverted over water to see blue over blue. Fly an approach into an airport adjacent to a city at night and see large bright blocks of obstacles obscuring your attempt to view the runway with natural vision).”

Table 13

Open-ended Text Responses When Asked, What do you Think Most Impacts the Benefit of a Synthetic Vision System

What do you think most impacts the benefit of a synthetic vision system?
• Updated database is critical, needs to be updated near real time in any type of head worn sustem • unreliable or error prone sources of data make synthetic vision useless and hazardous. Data has to be correct with the real world. • The source for obstacle and terrain information may not necessary lessen the operational benefit in and of itself, but it could be a mediating/influential external variable that impacts the operational benefit of SVSs in general. The frequency with which the SVS database is updated, the use of color/shape coding and signifiers, and the method for conveying SVS alignment performance are all factors that could vary depending on the source for information. The presence of this kind of variability could reduce the operational benefit because operational authorizations would have to be based on the lowest common denominator. • The obstacle DBs may not be as accurate as the terrain db's. For rotorcraft ops, this is important. An accurate, precise terrain db with a "photo realistic" depiction of terrain coupled with a sketchy obstacle DB can lead pilots into false sense of security. Additionally, one could argue that the more granular the terrain presentation could lead pilots to use the SV as a sole source of navigation and terrain clearance. There are systems where the SV

What do you think most impacts the benefit of a synthetic vision system?
terrain DB is not the same DB used by the TAWS/HTAWS system but present information regarding relative terrain similarly. • The amount of safety enhancement/operational benefit is directly proportional to the accuracy, currency, and fidelity of the obstacle and terrain information available. • system processor, HUD/HMD capability in accurately depict the outside scene (including ability to obtain optimum brightness/contrast • Synthetic vision alone lacks the ability for verification of aircraft position with something real on the ground. • Stale database. • Reliability and fault exposure(gps spoofing ie) • Overall situational awareness, but the concern would be for the validity of the data since it's not real time. • old or inaccurate database information • Of course the obstacle and terrain database affects ops benefit. • Location of the airport and runway center-line is the greatest benefit. Obstacles and terrain in a head up display add clutter and confusion (fly along a shoreline to see blue sky, and blue water with the shoreline seeming to be a banked horizon line. Fly inverted over water to see blue over blue. Fly an approach into an airport adjacent to a city at night and see large bright blocks of obstacles obscuring your attempt to view the runway with natural vision) • Inaccurate information displayed. • GPS jamming and spoofing are a hot topic in the industry. The idea that my GPS could be compromised and show me false images concerns me • Fidelity and currency of the database. • Current databases as well as the PVI displays. If the display is cluttered and does not provide any more relevant data to the pilot than existing displays, then it detracts from value • Call me 'old school,' but I don't believe in blocking out the real world when flying the plane. It's like saying we should all be driving our cars using camera displays of the outside world. • an out-of-date database. • accuracy and quality of the terraina nd airport DB directly affect the quality and comformity of the SVS imagery. A wrongly presented "synthetic runway" would per sse provide a misleading cue for the crew (and a very attractive one, if compared with the minimal viusual cues that the crew may have during LVO of the "real" runway).

Compellingness is a property of a display that may attract the pilot’s attention, at the expense of attention to other flight tasks or displays. One potential consequence of display compellingness, especially for SVSs, is that the display is so immersive, realistic, or compelling that it has a negative effect on decision making (e.g., operating in the visual segment of an approach when the requirements for the operation have not been met). When asked about SVS display compellingness, 60.0% (*n* = 36) of the 60 Experts who responded considered it to be a concern. The Expert respondents were asked about methods to address concerns that an SVS is so realistic, immersive, or compelling that it might lead to poor pilot decision-making. Themes for responses centered on training, pilot technique, and display design (Table 14). For example, recommendations included continuously executing a crosscheck, referencing the limitation section of the airplane flight manual (AFM) or rotorcraft flight manual (RFM), simulator training with an experienced instructor who provides constructive feedback, and training focused on scenarios that invoke cognitive tunneling when transitioning from the visual to instrument segment to promote targeted learning. Display design suggestions included turning off changing or flashing symbology (which are likely to draw attention), prohibiting photorealistic terrain depictions, and other design features such as automatic and graceful decluttering, especially at the decision altitude (DA)/DH of an approach. Regardless, there was some skepticism that training alone would be a sufficient countermeasure for any negative effects of display compellingness. One Expert respondent noted that "you can tell a pilot to "be careful" all you want, but even as a conscientious and careful pilot I've let SVS drive me into a rain shower, and land heedlessly in a night snow shower. This proves to me that training will not reduce this likelihood."

Table 14

Open-ended Text Responses When Asked, What Methods Have you Identified to Address any Concerns That a Synthetic Vision System is so Realistic, Immersive, or "Compelling," That it may Lead to Poor Pilot Decision-making Through Training or Design

What methods have you identified to address any concerns that a synthetic vision system is so realistic, immersive, or "compelling," that it may lead to poor pilot decision-making through training or design?
• You don't change how you fly, you continuously execute standard cross check and allow technology to enhance situational awareness with healthy skepticism • You can tell a pilot to "be careful" all you want, but even as a conscientious and careful pilot I've let SVS drive me into a rain shower, and land heedlessly in a night snow shower. This proves to me that training will not reduce this likelihood. • Turning off, color changing or flashing symbology • Training on IFR basics, show the effect of SVS drift in overall precision and situational awareness • Training is essential, but nowadays, my concern is the design, specially if it is based on GPS only. We are facing too many problems with GPS. I would be more confident with undependable system. • Training and design would help • training and design • Training • This is a hard HF problem and I do not think there is good solution. With time, pilots (humans) will tend to fully believe on the (DAL C) SVS. • There are some concept of phote-realsitc SVS, example is NASA X-59 aircraft. This is concern because photo-realistic SVS is VERY compelling. Not recommend to allow to use photo-realistic SVS . • The system has to be configured according to each procedure expected to be flow and trigger alerts and flight deck effects when operational conditions are not meet. • TASE, specific initial training and recurrent training on every EBT cycle • SVS DB may not be that accurate as we need: actually a typical angular shift is at all times observed on suthetic runway presentations, at time incorrect runway vertical plane was

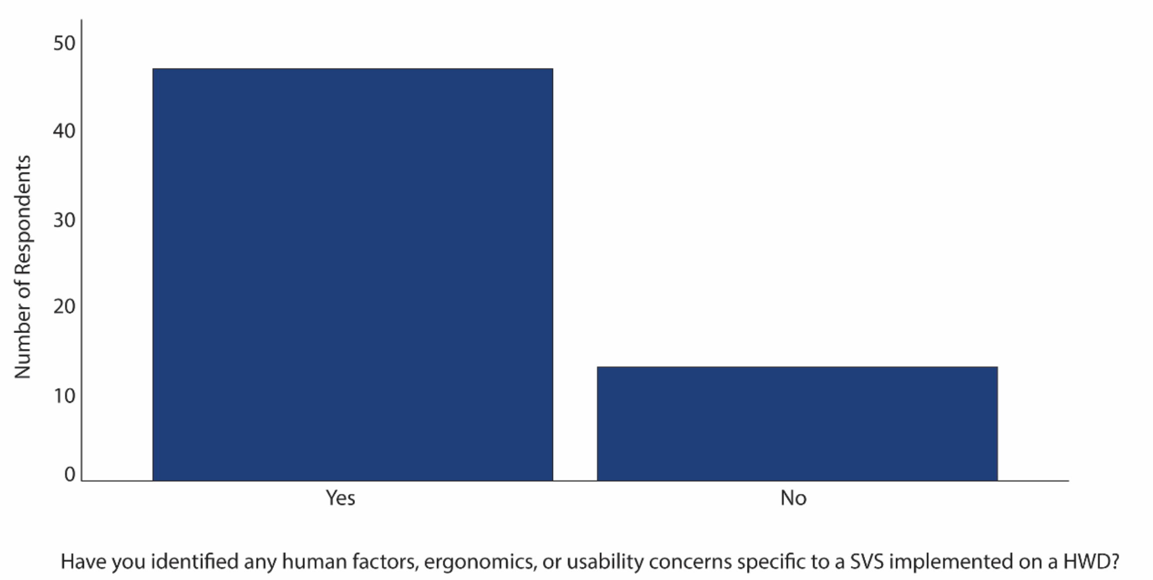
What methods have you identified to address any concerns that a synthetic vision system is so realistic, immersive, or "compelling," that it may lead to poor pilot decision-making through training or design?
also seen. These erroneous SVS presentations are misleading since he SVS picture is clearly more attractive and more visible than the "minimal" visual cues (or EFVS cues) that may appear in the very last stages of the approach • Represenation of SVS to differeratiate it from actual sensor imagery. How isobars are represented the SVS where the sensor image does not have that. • redundancy, error checking and clearing erroneous info, multi-sensor (CVS) cross cueing. • Proficiency. Simulator training with instructors who critique (call out) improper use of avionics. • Pilot education, but you can't cure the stupid pilot from using it in conditions that they are not qualified or rated to do. • Other than an AFMS/RFMS limitation stating that SV is not to be used as sole source of navigation or terrain avoidance, not sure. One display manufacturer does not provide "realistic" terrain depiction, keeping it "low resolution". According to them, they've received suggestions from pilots to increase the level of detail since the pilots cannot use the depiction to navigate mountain passes in low visibility, in violation of the RFMS limitation. • Only if what is presented does not reflect the real world situation. If it presents false data to the pilot, that can be detrimental. • make available approved training area of special emphasis (TASE) • Mainly training • It must be used as an addition to what information the pilot already uses, as an added situation awareness tool. • How to blend with other information or when SVS is available. Mostly training must address this. • For the specific operational scenario presented in the prompt, SVS could incorporate design features to mitigate tunneling. For example, SVS symbology that gracefully declutters, partially/fully disappears, or otherwise changes in a predictable, meaningful, non-distracting way at the DA/DH of the approach. CRM procedures could be designed to add redundant layers that protect against tunneling, as well. Training could incorporate scenarios designed to invoke tunneling when transitioning from the visual to instrument segment, to prompt targeted learning. • Clearly understandable guidance for the use of synthetic vision and training • Clearly specify the minimum visual cues and have PF and PM crew coordinate on presence of minimal cues • AFM limitation. Not for navigation. • Addressed through training • "SVS-on" indication shown on the display

Note. Crew Resource Management (CRM); Design Assurance Level (DAL); Evidence Based Training (EBT); Training area of Special Emphasis (TASE)

4.3.3 Human Factors, Ergonomics, and Usability of Synthetic Vision Systems Implemented on Head-worn Displays

When asked if there are any human factors, ergonomics, or usability concerns specific to an SVS implemented on an HWD, 78.3% (*n* = 47) of Expert respondents indicated “Yes” (Figure 6).

Figure 6
Have you Identified any Human Factors, Ergonomics, or Usability Concerns Specific to Synthetic Vision Systems Implemented on a Head-worn Display



Expert comments ranged a number of topics, including concerns for pilot comfort and fatigue (e.g., eyestrain, neck fatigue, extended wear, HWD shifting position over time, hot spots, effect of monocular vs. binocular optics); training and familiarity; view conformation (e.g., “the small but perceivable differences with actual terrain cause cognitive dissonance and distraction”); display clutter; interference with other procedures (e.g., donning an O_2 mask); and other similar concerns (Table 15). Some comments focused on routine operational tasks, such as the practicalities of carrying, cleaning, and maintaining the HWD. Other comments were related to the use of HWDs in operations, such as HWD crashworthiness; reduced ability to detect unexpected events in the external environment; the effects of display compellingness on the pilot’s attention; the effect of switching from an SVS image to a conventional display at severe bank angles (e.g., “If the pilot is not used to conventional displays, why remove SVS when they are in trouble?”); the effect of the visual image in different environments (e.g., “brightness of city skyline obstacles detract from visual approaches at night”; “flying parallel to a shoreline confuses the blue sky with blue water and perceived horizon”). The pilot’s perceived risk of the situation may also be affected, as evidenced by one comment from an Expert respondent: “I've flown headlong into a rain shower unaware because the background SVS on a HUD display lulled me into feeling like it was VMC”.

Table 15

Open-ended Text Responses When Asked, What are Your Concerns Specific to a Synthetic Vision System Implemented on a Head-worn Display

What are your concerns specific to a synthetic vision system implemented on a head-worn display?
• With the HWD, the pilot will have to spent "some" time to get used to it. The "some" time may be different for each pilot. Training is crucial and the most important factor is the adjustment for wearing comfort to prevent hot spots. • Weight of HWD, eye and neck fatigue, possible visual issues with prolonged use, monocular vs. binocular issues not common to all pilots. • Weight • Wear fatigue, loss of view due to eye position, application of technology to an operational environment (carrying it, cleaning, maintenance...) • Usability: SVS presentation need to be harmonized (conformity, brightness/contrast) to combine with the HUD/HMD basic (PFD) symbology and with eventual EFVS layer. Error detection: the SVS need to be presented by an inherent robust system, capable of monitoring the image quality and remove it when biased/mislaigned/corrupted. When SVS is reliable it allows the crew to execute a "consistency check" of the EFVS images, required to base piloting actions on the EFVS cues (e.g. maneouvring in short final on non precision approaches/ decision to continue through published DA/MDA or not, etc.) • Usability, lack of alerting, lack of conformality, lack of knowledge on the part of the prospective Part 91 user - many of whom have a hard time with modern avionics already - power issues (i.e., battery or corded?), crashworthiness • The weight, size (very small optical), latency and refresh rate, boresight, power supply and failure rates are amongst the issues. • The synthetic image is monochrome so seemingly lacks some of the goodness of the colored display on the PFD. • The first is related to the logistics of removing the HWD to put an O2 mask on and/or wearing one with an O2 mask on. The second is related to the most appropriate time to begin wearing the HWD during descent and approach or even during takeoff to avoid discomfort.. • The device must absolutely be calibrated and worn properly to insure it does not blank. • System needs to be ergonomically designed and take into account the human visual system • SVS is typically reverted back to conventional display at severe bank angles to facilitate upset recovery. If the pilot is not used to conventional displays, why remove SVS when they are in trouble? Brightness of city skyline obstacles detract from visual approaches at night. Flying parallel to a shoreline confuses the blue sky with blue water and perceived horizon. SVS heads up adds unnecessary clutter in all flight phases. The small but perceivable differences with actual terrain cause cognitive dissonance and distraction. Head up SVS distracts from airborne threats (I've flown headlong into a rain shower unaware because the background SVS on a HUD display lulled me into feeling like it was VMC). SVS also doesn't show live hazards on the runway. SVS is not appropriate for heads up. Its marginally OK when combined with EVS. The only elements of SVS suitable for head up are runway centerline and airport locator. Head worn displays require care and attention to maintain proper placement. This means the safe outcome of an approach is contingent upon how the pilot maintains the fitment of the device on their head, which is unpredictable and uncertain. Head worn adds this risk to low visibility approaches. Headworn devices I've experienced naturally shift position with head movement and need

What are your concerns specific to a synthetic vision system implemented on a head-worn display?
frequent adjustment. If you tighten it enough so that it doesn't move it is very uncomfortable. • setup/adjustment of HWD hardware; image resolution and fidelity when compared to cockpit displays and HUD; ease of use (bulky hardware shall be avoided); • see research reports by NASA. see also RTCA DO-315[8] et al. • Better fidelity of data viewed. • Quite a lot of research into benefits and drawbacks of SVS on HUD has been done over the years; the findings from that research could apply to the HWD as well. Chief among them being detection of unexpected events in the external environment. The compellingness of the SVS image has been shown to bias pilots' attention away from the external environment, hindering their ability to detect unexpected obstacles (e.g., other air traffic in the air and on the runway). This effect may be exacerbated with an HWD that has a wide SVS field of view. The compelling SVS image may reduce pilots' ability to detect unexpected events to the side of the aircraft. • Pilots may rely on it as a source or real time information, even though data base driven. • Pilot comfort, some pilots reported feeling dizzy while using it for some time. The weight of the HMD also causes some discomfort for prolonged use. • Not necessarily concerns but use case considerations to be validated and addressed by design • neck fatigue, headaches, functionality in poorly sized cockpit • movement of HWD, turbulence, eye reference focusing • Monocular view, head worn structure in your head, symbology definition, use of colors • Major concern is that prescriptive rule making will simply force the head worn display to display primary flight information. The head worn display needs to display critical data in a clutter free format. Example airspeed. Adding an airspeed tape to a head worn display is missing the entire point. Head on display should convey ON- Speed or AOA margin. This can be conveyed with visual ques in the periphery of the field of view. A head worn display should be a game changer and we should question all of our existing rules on how we display information to the pilot. • Latency • It blocks out the outside world. • Interfacing harness assembly can become an obstacle or become entangled • If the obstacle database is not current - usability issue. Ergonomic/human factors - HWD could be bulky/too heavy. • I feel that SVS on a head-worn device or a HUD may occlude the outside environment. • HWDS in general: HWDs can be uncomfortable especially for longer durations; need to consider if/how it is integrated with other equipment on the head (communication headset, oxygen mask, etc.). Specific to SVS On HWDs: Ability to choose what aspects of SVS are shown on the HWD (including to turn off - per regulation), brightness controls, and how it is merged/overlaid with EVS information.

[8] RTCA. (2011). Minimum Aviation System Performance Standards (MASPS) for Enhanced Vision Systems, Synthetic Vision Systems, Combined Vision Systems and Enhanced Flight Vision Systems (No. DO-315B).

What are your concerns specific to a synthetic vision system implemented on a head-worn display?
• How transparent is the display? What flight guidance information is presented and how? See SAE ARP 8459[9] • Head-worn displays can be heavy and uncomfortable to wear for long periods of time. Ergonomics must be adequately accounted for in the design of the device to ensure discomfort does not detract from the benefits provided by the display. • Head worn displays have unique challenges with regards to fit and comfort (weight, center of gravity, head worn display motion relative to eye during head movements and turbulence), display latency, display resolution. • Glow and being too brite. The HWD also has to properly “blank” when the pilot is looking through the HUD to avoid double images. The system has to allow the pilot to quickly adjust his eyes to focus at infinity to see the HWD, the instrument panel, and back to the runway. While it would be ideal to have the PF just look through the HWD - that can’t always happen. • For monocular solution, the "construction" of the full picture can be difficult • Fitment and configuration is somewhat more complicated than say a HUD. Extended wear of HWD may become more obtrusive than HUD. • Field of view, latency, jitter • Eye and/or neck fatigue. • Ease of donning. Comfort when wearing. Ensuring the device is calibrated between the real world and the avionics. If the first two are not made convenient, users will choose not to use. • Depending on monocular or binocular can cause issues like fatigue and headaches. Depending on display size and shape may interfere with some peripheral visual information. • Conformal view vital to utility of HWD. If not conformal (to outside world), causes mental disconnect. • Concerns are more about the head-worn display response to head tracking and movement more than SVS being on a head-worn display. • Concerns are common fit, weight, fatigue on long-haul missions for HWD. Additionally, the need for precise alignment to ensure a stable display results in significant upkeep on behalf of both the pilot as well as support • Comfort of head-worn display, donning and doffing time, time to align HWD for adjust alignment and focus. • Accuracy, latency and optical performance. Monocular solutions leading to rivalry - increased workload and loss of attention. • A pilot needs to be able to separate the SVS from the actual sensor images. They need to know what is real time and what is synthetic. This provides the knowledge of what to trust as real-time and what is added in as additional information. Pilots need to know what to trust as the actual situation.

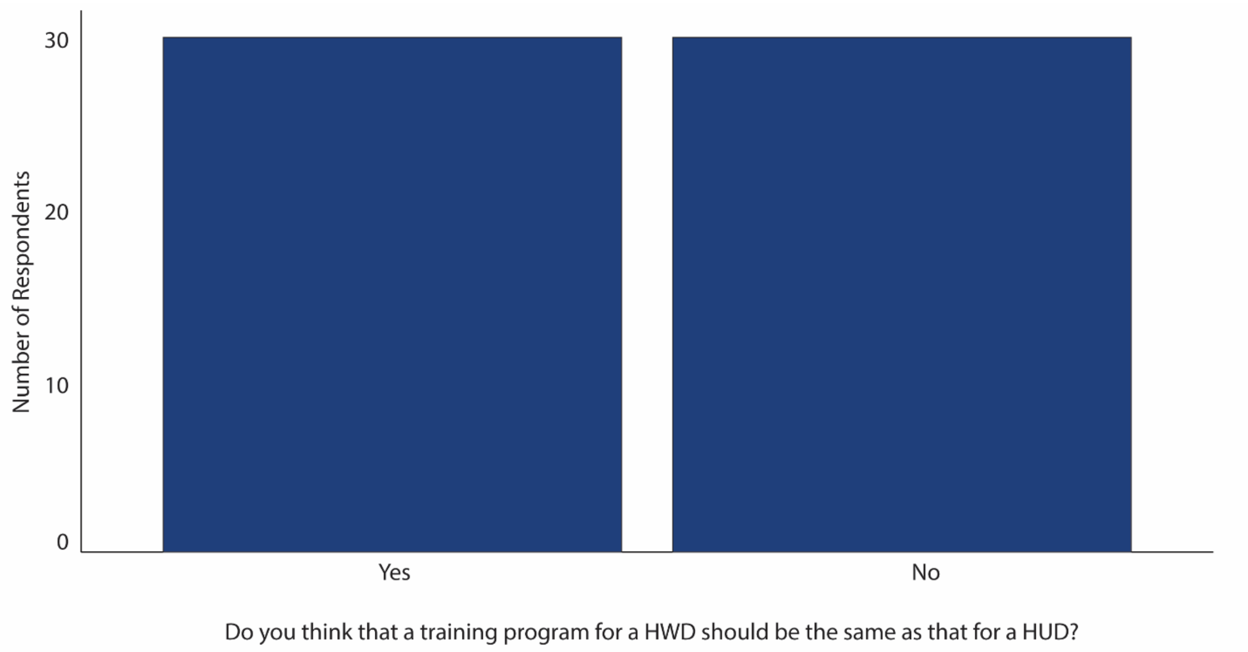
Note. Angle of Attack (AOA)

[9] SAE. (Forthcoming). Human Engineering Considerations with Implementation of Aided Flight Vision for Vertical Flight Platforms All Weather Operations (No. ARP8459).

4.3.4 Training for Synthetic Vision Systems and Head-worn Displays

The Expert respondents were evenly split on whether training for using an HWD should be the same as for an HUD. Of the 60 Experts who responded to this question, 50.0% (n = 30) indicated that the training should be different, and 50.0% (n = 30) indicated that the same training would be effective (Figure 7).

Figure 7
Do you Think That a Training Program for a Head-worn Display Should be the Same as for a Head-up Display



Expert respondents were asked if there should be special training considerations for different phases of flight if the SVS is implemented on an HWD. Each phase of flight was asked as a separate question. Of those who indicated the need for special training considerations for different phases of flight, the two most-frequently selected were Taxi (60.0% Yes; n = 33) and Takeoff (56.0% Yes; n = 28; Table 16).

Table 16
Special Training Considerations for the use of a Head-worn Display During Phases of Flight

	Respondents (n)				
Flight Phase	**Yes (n)**	**Yes (%)**	**No (n)**	**No (%)**	**Total (n)**
Taxi	33	60.0	22	40.0	55
Descent	17	33.3	34	66.7	51
Landing	23	45.1	28	54.9	51
Rollout	22	43.1	29	56.9	51
Takeoff	28	56.0	22	44.0	50
Climb	18	36.7	31	63.3	49
Cruise	13	26.5	36	73.5	49
Missed Approach	17	35.4	31	64.6	48
Balked Landing	16	34.0	31	66.0	47
Total	187	41.5	264	58.5	451

Note. Each Flight Phase was presented as a separate question item.

When Expert respondents were asked for additional training considerations specific to HWDs, common themes among responses included: HWD fitment, boresighting, vision compatibility with the monocular or binocular optics of the HWD, alignment of symbology, and use of the expanded field of view or field of regard (Table 17).

Table 17

Open-ended Text Responses When Asked, What Additional Training Considerations Should be Considered for a Head-worn Display

What additional training considerations should be considered for a head-worn display?
• Weight. Field of view. • Training to don (for accuracy and comfort). Training to doff (if required) in non-normal conditions (and where to put the HWD to not interfere with the flight). Any HWD model-specific aspects to be reminded of, such as if there is boresighting. • Training should account for any differences, such as the relative movement of attitude information during head movements • There are fundamental differences between the two systems that should be addressed in training. • The wearing of an HWD is very important • specific characteristics and way of working which is different from HUD • Some sort of medical test to ensure vision is compatible with monocular/binocular configuration of the HWD chosen. SOP on when the HWD is allowed to be used based on ergonomic concerns (i.e., eye and neck fatigue). Some consideration of pilot head movement vs. displayed scene would be helpful too. • Similar but not exactly the same. It all depends on what info is displayed. • Proper fit and operating limitations • Not familiar with head-worn systems. Training must be tailored to each system used. • Limitations of the system as to how far up and down or left and right the HWD can provide information. • It is an additional safety feature, it should be treated the same as when SVS was added to displays or AOA heads up. • I'm not familiar enough with HWD, however, key elements (type specific) of a HWD training have to be determined by the OEM. • HWD can be more overwhelming if not trained • How and when to put on/take off HWD; how to align HWD symbology; how to calibrate HWD for interpupillary distance and vertical ocular offset; how to utilize expanded field of view/field of regard of HWD, if applicable. If pilots use eyewear/corrective lenses while they fly, training should address how to use HWD over eyewear/corrective lenses. If HWD is monocular, training should familiarize pilots with unique attributes of monocular symbology. Training should target HWD failure scenarios, including whether to leave HWD on during failure or take it off, whether/when to transfer control. • HMD has differnet (and additoina) "threats" for the crew than the HUD (angle of view, head movements, head positioning, fatigue, monocular vision) • head worn is more invasive. • head worn is more complicated. • FOV, parallax, correct wearing and adjustment • Fitting the device, procedures in the event the visual system is disrupted. • field of regard is different, need to train specifically for this. Study the effects of head movement (spatial disorientation) • Eye position, monocular vs. binocular view, distant vs. near runway eye focus transition

What additional training considerations should be considered for a head-worn display?
• Donning and doffing, whether display content changes depending on where you are looking. • Depending on the technology, there is a need to adapt the workload between head up and head down while info are still available even partially • Appropriate head movements • Additional use in taxi, runway entry/exit • A headworn display needs constant care and feeding to ensure fitment. The safe outcome of an approach will be contingent on the pilot making proper adjustments, and you don't really know you have it misaligned unless you intentionally do a calibration check. Its also imperative to prevent yourself from aligning your head to the device; rather, you must align the device to your head. It's hard to explain unless you've done it, but it really makes a difference.

Note. Angle of Attack (AOA); Standard Operating Procedure (SOP).

The Expert respondents were asked to provide examples of initial pilot training topics to learn to use an SVS for taxi (Table 18), as well as any special considerations specific to SVS on an HWD for taxi (Table 19). In general, the Experts recommended training on symbology, surface markings, taxiway location, and signage. Traffic identification, maintaining a visual scan, differentiating synthetic from real-world imagery, understanding limitations of the conformal view, and continuing normal taxiing procedures were also mentioned. Focusing on Expert recommendations specific to SVS on an HWD, training recommendations were centered on understanding limitations of the SVS on an HWD and techniques to ensure the SVS does not occlude critical elements in the external scene.

Table 18

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for Taxi

What topics should be covered during initial training to learn to use a synthetic vision system for the taxi phase?
• Which aspects may be more accurate than others (e.g., the source of the information), such as taxiway location / width, surface markings, signage. • What it should not be used for. i.e. vis is too low to takeoff Limitations of the system during taxi phase. • what is in the data base vs what is not • use brightness so that outside view is always possible: SVS conformal presentation is not always 100% precise, traffic (a/c, ground personnel, vehicles are not presented); colors and sings would not be presented as they are; NOTAMS not accounted for; in general on CVS the EFVS layer is to be favoured in HUD/HMD for ground ops, SVS may be used to keep awareness of rising terrain around the field, symbolgy must not block natural vision. • understanding brightness control, head-up/head-down time allocations • Type of lighting and signage that will show. Type of other aircraft lighting. • Turn it off. Don't use it. You should be looking outside. SVS imagery blocks, obscures, and distracts your natural vision. The condition and safety of the taxi route are not depicted by

What topics should be covered during initial training to learn to use a synthetic vision system for the taxi phase?
SVS. The only head up cues that might be worthwhile would be a subtle route indicator that can easily be disregarded. • To not relay on the image and look outside • System limitations. Crew coordination. Procedures • system error sources and correction, cross cueing. • Symbology, position accuracy and non-normals • Symbology, effects of latency • Symbology usage of taxiways and other things that are put on the display to help augment the pilot's understanding of the taxi environment. • SVS failure modes, what do they look like, how are they presented? • Signage, markings, surface identification, illusions and omissions observed. Limits of the synthetic vision. • Should be developped as type specific • Precision of the whole system is not sufficient to rely only on SVS to remain on a taxiway • normal, failure and bypass modes. • low visibility, makings, signs, symbology • Limitations of the SVS, symboloy, alerts, procedures for SVS fail during low visibility operations. • limitations of svs (stale data) • Learn about adjusting brightness/contrast. • Just the limits of the system and what it does and does not do. • It depends on the build of your synthetic system. Again, this is not my area of expertise • Interpreting the synthetic vision information against the real surrounding terrain • and recognition of degradation due to system failures or any other issue leading to less than required safety level • Intended function, procedures for use of charts, moving map, and synthetic vision displays. • How compelling it is and not to be drawn into SVS as the complete picture. • External signage and traffic detection. Situational awareness should be intuitive, however if EVS is not a part of the display, then the limitations of the system should be discussed. • Don’t use for navigation interpretation of all symbology. • Don't rely 100% on the SVS. Keep a normal scan. • Do not forget/stop using traditional methods such as WRITING DOWN THE TAXI CLEARANCE. • Configuration, including setting of brightness, contrast including global and specific layer properties. • Capabilities and limitations of imagey and information displayed • brightness optimum adjustment, outside scanning technique, CRM (PF, PM roles), SOP adaptation • Basic use, when to use, when does it provide benefit (night, low vis, or high complexity surface map) • Basic training on differentiate real vs synthetic info

What topics should be covered during initial training to learn to use a synthetic vision system for the taxi phase?
• Basic symbols representing obstacles • Assuming an SVS is shown to be reliable and accurate for taxi or as an "aid" to supplement visual taxi? • All phases when system is worn • Airport moving area maps, traffics on the ground, moveable objects etc… • Airfield lighting/signage recognition. • Accuracy of real scene vs. SVS scene should be demonstrated and knowing when to disregard SVS scene..

Note. Crew Resource Management (CRM); Notice to Airmen (NOTAM); Standard Operating Procedure (SOP)

Table 19

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Taxi Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the taxi phase, if yes, please provide examples.
• Very hard to properly design. From experience, the experimenta models tested were inadequate. I have touched on some of the issues previously and will leave it to the designers to expend. • Turn off the SVS because the obstacle, terrain, and runway cartoon imagery will block your view of the actual taxi way and threats. • Training in required for a head born display. Synthetic vision for SA can run in the background with no training required. • There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi. • the crew may use the HMD offboresight and get awareness of the environment on the sides of the a/c. However, this need not cause dizzines/sickness in the crew; main threats for this are possible slight SVS latency or correct horizion alignement issues. • the ability to add 360 degrees and not to add SVS on top of needed flight display information and controls • Symbology size, format and color, head worn display structure, head positioning tracking • SVS on a HWD may occlude the outside environment. • since HDD repeater for PM displays what the HWD is aiming at, proper SOP and CRM should be adapted for HWD operations during taxi • setup of hardware and calibration/ adjustment • Symbology, effects of latency • proper eye alignment • Poor fidelity

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the taxi phase, if yes, please provide examples.
• Operational limitations consistent with specific airplane level safety case and operations • Occluding OTW visibility • Limitations of display to provide information - colors, resolution, image fidelity • It would have to be perfect. the image would be more distracting, and the pilot could rely on that as a sole source • Instruction on head motion necessary to see symbology...may need to turn their head more depending on HWD field of view • Importance of proper fit and alignment • If combine with enhanced, there needs to b cut out in landing phase so a real image takes priority. • I guess if the HWD were/were not configured for off boresight vision, this might confuse the cockpit situation. • How is attitude information provided when looking off axis? What is the FOV vs the FOR? How is distance information in the X axis provided and how intuitive is it or does the pilot need to access another display for that information? What are the refresh rates based on pilot head movement velocity? How stable is the image regarding jitter or vibration? What is the effect of pilot-display coupling regarding display vibration and clarity? See SAE ARP 8459[10] • For Both pilots when flying multi crew?, back up system I still head-worn? • Fitment and initial configuration. • Field of regard, blanking to account for unimpeded view of internal switches and displays. • Field of regard, behavior when looking sideways • Don't block out the real world. • Continually look around as you would normally. • Care not to rely only on the system for movement, possibility of false information • brightness control, clutter and obscuration • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.). • Accurately overlaying information on the real-world is very important because of how close the outside world is (any inaccuracy would be noticeable).

Note. Crew Resource Management (CRM); Out the Window (OTW); Standard Operating Procedure (SOP)

For takeoff, Expert respondents recommended initial training topics similar to those for taxi. Some additional recommendations included scenario-specific training, such as engine failures during takeoff at different reference speeds, the effect of crosswinds, crew coordination, and SVS limitations (Table 20). Specific to SVS on an HWD, Experts again provided recommendations similar to those for taxi. Additional recommendations for takeoff focused on training for failures and emergencies, and understanding SVS on an HWD limitations (Table 21).

[10] SAE. (Forthcoming). Human Engineering Considerations with Implementation of Aided Flight Vision for Vertical Flight Platforms All Weather Operations (No. ARP8459).

Table 20

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for the Takeoff Phase

What topics should be covered during initial training to learn to use a synthetic vision system for the takeoff phase?
• what the runway cues are • Use the SVS as a backup to what you see outside • Turn it off, do not use it. Synthetic vision blocks, obscures, and distracts your natural vision out the transparent windshield • System limitations. Crew coordination. Procedures. • System failures , alll • symbology, pitch attitudes, vertigo, head movement, V1 & V2[11] engine failures, crosswinds • Symbology and cueing • SVS should not be actively used for takeoff • Which aspects may be more accurate than others (e.g., the source of the information), such as taxiway location / width, surface markings, signage. • Capabilities and limitations of imagey and information displayed • normal, failure and bypass modes. • Precision of the whole system is not sufficient to rely only on SVS to remain on a taxiway • interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level • Should be developped as type specific • Proper runway marking recognition. • pretty much the same today are covered for LVO plus: - PM duties/call outs via HUD/HDD repeater - SVS failures management • Limitations. Failures. • Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations • limitations of system • limitations of SVS • Limitations associated with the display of SV vs. EVS. • Learn about adjusting brightness/contrast. • Interpreting the synthetic vision information against the real surrounding terrain • Intended function, operational procedures, proper fit and alignment. • Illusions, limitations. • If a takeoff reject is made for reasons only the HUD/HWD pilot sees - CRM must be used to verbalize/communicate the reject decision to the unaware pilot.

[11] V1 is the maximum speed at which a pilot can stop an aircraft on the runway after acceleration if a takeoff is canceled. V2 is the minimum speed required to ensure the aircraft can climb safely and reach a safer altitude if one engine fails during takeoff.

What topics should be covered during initial training to learn to use a synthetic vision system for the takeoff phase?
• How to use. • How compelling it is and not to be drawn into SVS as the complete picture. • Failure modes • Ensure alignment with actual runway and confirm taking correct runway for takeoff. • Don't rely just on the SVS. • do not block real vision; do not just rely on SVS imagery, do not block PFD HUD/HMD symbology, avoid distraction/focusing on non pertinent details/items (clutter): for CRM, consider possible different SA for the OM (if not provided with SVS). • Configuration, including setting of brightness, contrast including global and specific layer properties. • brightness control, clutter • Basic symbols representing obstacles • Appreciation of the distances in a synthetic world • All phases of flight need to emphasize a thorough cross check • All • Address limitations of the system and malfunctions. Also address what is primary for decision making vs. what is to be used as an aid. SVS is not a navigation source, just a vision aid.

Note. Crew Resource Management (CRM)

Table 21

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Takeoff Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the takeoff phase, if yes, please provide examples.
• train where to look for needed information and what is SVS and what is not • Symbology size, format and color, head worn display structure, head positioning tracking • Which aspects may be more accurate than others (e.g., the source of the information), such as taxiway location / width, surface markings, signage. • Symbology usage of taxiways and other things that are put on the display to help augment the pilot's understanding of the taxi environment. • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.). • Symbology and cueing • SVS should not be actively used for takeoff • Limitations of display to provide information - colors, resolution, image fidelity • Obscuring OTW • All • setup of hardware and calibration/ adjustment • possible disorientation or fatigue due to incorrect wearing/adjustment of HWD

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the takeoff phase, if yes, please provide examples.
• pitch attitudes, colors, eye strain, focal distance recognition, crosswinds • not familiar enough with HWD • Minimize glare and glow. It must blank when the pilot is looking into the HUD or PFD. It must allow the pilot to focus at infinity like the HUD. • Intended function, operational procedures, proper fit and alignment. • If the HWD were/were not configured for off boresight vision, this might confuse the cockpit situation. • Headworn transfers the obscuring effect of the SVS cartoon in every direction you look, not just in the HUD straight ahead. • Head motion • Field of regard of synthetic vision • Fidelity • failure cases of the HMD: turn it off immediately to recover binocular vision, set brightness/contrast so to avoid clutter/blocking other imagery and data (e.g. PFD), keep head alignement in the direction of the path (rearely but surprisingly observed: one pilot tried to fly the path by moving the head... not actually turning the a/c... spational disorientation may always be a threath when we deal with artifical vision systems) • don't rely on it too much • Don't block out the real world. • brightness control, clutter, nav accuracy • Backup system, contingency procedures.

Note. Out the Window (OTW)

For climb, Expert respondents provided initial training recommendations similar to those previously mentioned for other phases of flight. In addition, terrain and obstacle recognition, pitch attitudes, failures and emergencies, standard instrument departure (SID) procedures, and limitations were discussed (Table 22). Specific to SVS on an HWD, the Experts also recommended training on the effects of the HWD field of regard (Table 23).

Table 22

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for the Climb Phase

What topics should be covered during initial training to learn to use a synthetic vision system for the climb phase?
• typically SV on a climb-out is worthless. Terrain is out of the field of regard. • Turn it off. SVS cartoon imagery obscures and distracts your natural view out the transparent windshield. • The same as other phases of flight • Terrain and obstacle recognition and well as divert airfield identification. • symbology, pitch attitudes, vertigo, head movement, V2 and above engine failures

What topics should be covered during initial training to learn to use a synthetic vision system for the climb phase?
• SID use. Proper speed to fly (Vy or Vx)[12] if in a lower-powered aircraft. • Should be developped as type specific • Capabilities and limitations of imagey and information displayed • interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level • System failures , alll • Appreciation of the distances in a synthetic world • Symbology and cueing • normal, failure and bypass modes. • Priority to external natural vision (and WX on PFD/MFD) for weather detection and preventive A/I activation, eventual traffic detection • Limitations of the SVS, symboloy, alerts • limitations of SVS (what type of data is shown) • Limitations associated with SV vs. EVS or natural vision. • Learn about adjusting brightness/contrast. • Intended function, operational procedures, proper fit and alignment. • Illusions, limitations. • How compelling it is and not to be drawn into SVS as the complete picture. • failure modes • depends on system implementation. But the specifics and limitations of the implementation are important • Configuration, including setting of brightness, contrast including global and specific layer properties. • Clearing using the HWD • Basic use. • Basic representation of obstacles • All that apply when receiving synthetic infections

Note. Multifunction Display (MFD)

[12] Vx is the speed that provides the best angle of climb. Vy is the speed that provides the best rate of climb.

Table 23
Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Climb Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the climb phase, if yes, please provide examples.
• There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi.
• Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.).
• Limitations of display to provide information - colors, resolution, image fidelity
• setup of hardware and calibration/ adjustment
• For Both pilots when flying multi crew?, back up system I still head-worn?
• Care not to rely only on the system for movement, possibility of false information
• Realization that the presentation is conformal and may require different head movement as compared to HDD.
• pitch attitudes, colors, eye strain, focal distance recognition
• not familiar enough with HWD
• Intended function, operational procedures, proper fit and alignment.
• Headworn transfers the obscuring effect of the SVS cartoon in every direction you look, not just in the HUD straight ahead. You can't turn your head to get away from the distracting and view-blocking SVS imagery.
• Field of regard
• fatigue due to wearing the HMD. In non essential phases of flight for SVS, the HMD should not be worn
• Don't block out the real world.
• brightness, clutter

For cruise, Expert respondents provided initial training recommendations similar to those previously mentioned for other phases of flight, with additional comments related to understanding alerting information (e.g., TCAS) and system limitations (Table 24). Specific to SVS on an HWD, the Experts also recommended training on pilot discomfort and fatigue related to wearing an HWD for an extended period of time (Table 25).

Table 24

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for the Cruise Phase

What topics should be covered during initial training to learn to use a synthetic vision system for the cruise phase?
• Turn it off. SVS imagery in the HUD blocks and obscures your view of traffic and terrain.
• The same as other phases of flight
• Terrain and obstacle recognition and well as divert airfield identification.
• Symbology, effects of latency
• Should be developped as type specific
• Capabilities and limitations of imagey and information displayed
• interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level
• Airport moving area maps, traffics on the ground, moveable objects etc…
• use brightness so that outside view is always possible: SVS conformal presentation is not always 100% precise, traffic (a/c, ground personnel, vehicles are not presented); colors and sings would not be presented as they are; NOTAMS not accounted for; in general on CVS the EFVS layer is to be favoured in HUD/HMD for ground ops, SVS may be used to keep awareness of rising terrain around the field, symbolgy must not block natural vision.
• normal, failure and bypass modes.
• obstacle clearance depiction
• Limitations of the SVS, symboloy, alerts
• Limitations of SV vs. EVS and natural vision. This is the least useful phase of flight for HUDs.
• Intended function, operational procedures, proper fit and alignment.
• I wouldn't suggest an SVS for cruise.
• How compelling it is and not to be drawn into SVS as the complete picture.
• failure modes
• Configuration, including setting of brightness, contrast including global and specific layer properties.
• appropriate uses
• Any information received, most likely TCAS info
• accuracy of svs

Note. Notice to Airmen (NOTAM)

Table 25

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Cruise Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the cruise phase, if yes, please provide examples.
• There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi.
• Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.).
• Limitations of display to provide information - colors, resolution, image fidelity
• setup of hardware and calibration/ adjustment
• For Both pilots when flying multi crew?, back up system I still head-worn?
• Care not to rely only on the system for movement, possibility of false information
• the crew may use the HMD offboresight and get awareness of the environment on the sides of the a/c. However, this need not cause dizzines/sickness in the crew; main threats for this are possible slight SVS latency or correct horizion alignement issues.
• Care not to rely only on the system for movement, possibility of false information
• same as for climb: avodingin increased fatigue and pilot comfort should be prioritized. At higher speed the a/c turns would also turn out increasing Nz: the HMD would weigh more on pilot neck!
• Symbology, effects of latency
• not familiar enough with HWD
• Intended function, operational procedures, proper fit and alignment.
• Headworn transfers the obscuring effect of the SVS cartoon in every direction you look, not just in the HUD straight ahead. You can't turn your head to get away from the distracting and view-blocking SVS imagery.
• Don't block out the real world.

For descent, Expert respondents provided initial training recommendations similar to those previously mentioned for other phases of flight. Additional comments were related to understanding what the database is representing during descent, divert, and destination airfield identification, display brightness and contrast adjustments, and system limitations (Table 26). Specific to SVSs on an HWD, the Experts recommended training similar to other phases of flight (Table 27).

Table 26

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for the Descent Phase

What topics should be covered during initial training to learn to use a synthetic vision system for the descent phase?
• When it should be worn and the limitations associated with SV vs. EVS or natural vision.
• what the database is representing in this phase.
• Turn it off. SVS imagery is distracting and covers over natural vision.
• Use the SVS as a backup to what you see outside
• terrain/obstacle review
• terrain clearance, normal and fail modes
• Terrain and obstacle recognition and well as divert and destination airfield identification.
• Symbology, position accuracy and non-normals
• symbology, pitch attitudes, vertigo, head movement, V2 and above engine failures
• Should be developped as type specific
• Capabilities and limitations of imagey and information displayed
• interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level
• System failures , alll
• Same as for climb and cruise. however when descending through lower levels/altitudes the use of SVS would become more interesting to increase SA of terrrain/obstacles
• Basic training on differentiate real vs synthetic info
• Symbology and cueing
• Recognizing special symbology that may be used in the descent approach and landing..
• No changes from current planning and briefing; but still brief it and contingencies if the HWD/SV fails.
• Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations, procedures for SVS fail during Low Visibility Operations.
• limitations and system design. What are limitations of navigational accuracy and how does that play into display
• Learn about adjusting brightness/contrast.
• Intended function, operational procedures, proper fit and alignment.
• Initial obstacle detection, limitations, illusions.
• I wouldn't suggest using SVS for descent - pilot fatigue issues.
• How compelling it is and not to be drawn into SVS as the complete picture.
• failure modes
• Configuration, including setting of brightness, contrast including global and specific layer properties.
• Clearing during descent
• brightness control, clutter
• Basic use, visual segment use permissibility, when to go around.

What topics should be covered during initial training to learn to use a synthetic vision system for the descent phase?
• Basic representation of obstacles and runway • Any that apply when receiving information • Accuracy of svs

Table 27

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Descent Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the descent phase, if yes, please provide examples.
• There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi. • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.).same as the previous question • Limitations of display to provide information - colors, resolution, image fidelity • Backup system, contingency procedures. • Care not to rely only on the system for movement, possibility of false information • do not block real vision; do not just rely on SVS imagery, do not block PFD HUD/HMD symbology, avoid distraction/focusing on non pertinent details/items (clutter): for CRM, consider possible different SA for the OM (if not provided with SVS). : HMD should be used when closer to terrain • Training in VMC and IMC to VMC transition. • pitch attitudes, colors, eye strain, focal distance recognition • not familiar enough with HWD • Intended function, operational procedures, proper fit and alignment. • HWD presentation is not as detailed • Headworn transfers the obscuring effect of the SVS cartoon in every direction you look, not just in the HUD straight ahead. You can't turn your head to get away from the distracting and view-blocking SVS imagery. • Field of regard • Don't block the real world • As previously mentioned

Note. Crew Resource Management (CRM)

For landing, Expert respondents provided initial training recommendations similar to those provided for other phases of flight. In addition, identifying map shifting or misalignment was mentioned (Table 28). Specific to SVS on an HWD, the Experts also recommended training similar to other phases of flight (Table 29). One Expert provided an example to emphasize the importance of training on limitations of SVSs on an HWD, “Landing south at Boeing Field at night, I looked left and saw the bright city skyline obstacles, which became an amorphous blob confusing my mind. I then tried to dim the imagery down to reduce the effect, but then then it was too low to be useful for runway imagery. SVS is just not appropriate for head up or head worn. EVS is more appropriate.”

Table 28

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for the Landing Phase

What topics should be covered during initial training to learn to use a synthetic vision system for the landing phase?
• Unless future operations requires SVS for landing, then the term "learn to use" is not appropriate (this applies to all previous phases of flight). Depending on the quality of the design, It could be used during specific non-normal situations affecting the guidance system in low visibility weather. This is not yet approved by the certification authorities.
• Use the SVS as a backup to what you see outside
• Terrain and obstacle recognition and well as divert and destination airfield identification.
• System limitations.. Crew coordination. Procedures.
• symbology, pitch attitudes, vertigo, head movement, crosswinds
• Symbology and cueing
• Which aspects may be more accurate than others (e.g., the source of the information), such as taxiway location / width, surface markings, signage.
• Should be developped as type specific
• Capabilities and limitations of imagey and information displayed
• Capabilities and limitations of imagey and information displayed
• interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level
• Airport moving area maps, traffics on the ground, moveable objects etc…
• Basic training on differentiate real vs synthetic info
• Review procedures for a possible map shift via database driven scene vs. actual view out the window. Discuss crew coordination if SVGS is only installed on one side of cockpit.
• Required visual cues. Effective techniques to declutter and confirm visual contact.
• Recognizing special symbology that may be used in the descent approach and landing. Cues that may be added to support landing and flare.
• Maintain a normal scan.
• Limitations. Failures.
• Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations, procedures for SVS fail during Low Visibility Operations
• limitations of system design and how nav accuracy plays into display of screen

What topics should be covered during initial training to learn to use a synthetic vision system for the landing phase?
• Likely this is the most critical phase for CVS or SVS. How it is used to follow EFVS rules, what credits it grants for reduced minima, how to use it.... too much to add for this survey. • Learn about adjusting brightness/contrast. • Interpreting the synthetic vision information against the real surrounding terrain • Intended function, operational procedures, proper fit and alignment. • Illusions, obstacle avoidance, conditions for an acceptable landing. Emergency landings, and how to determine water from land or solid objects. • If on HUD/HMD: oPtimization of the picture (brighness, contrast, cut out angle for CVS), awareness of credits that could be attained in the RVR and or DA/MDA, if EFVS is used, awareness of the consistency check against SVS and PFD approach data, Potential for failures and how to quickly remove SVS when disturbing. • Identification of synthetic vs natural cues. • How compelling it is and not to be drawn into SVS as the complete picture. • failure modes • Effect on possible drifting on overall accuracy of the approach • Dont use for landing. It's a reference for SA during approach phase. • Current procedures/training is sufficient. • correct brightness/contrast settings, failures management/ SOP callouts • brightness control, clutter, • Basic representation of obstacles and runway • At what distances is the database presenting landing information and what are the visual ques • Assuming no EVS, limitations associated with DH/DA if any credit is given. Limitations associated with SV vs. natural vision. • All that apply on the display • Adjust the brightness low enough to match ambient lighting. Turn off the SVS terrain and obstacle function if possible and only use the airport locator and extended centerline for awareness. • accuracy of svs (acceptable misalignment between SVS and natural vision)

Note. Standard Operating Procedure (SOP)

Table 29

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for the Landing Phase, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for the landing phase, if yes, please provide examples.
• Symbology size, format and color, head worn display structure, head positioning tracking • SVS on a HWD may occlude natural vision and actual runway environment identification. • Accurately overlaying information on the real-world is very important because of how close the outside world is (any inaccuracy would be noticeable). • There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi. • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.). • Limitations of display to provide information - colors, resolution, image fidelity • setup of hardware and calibration/ adjustment • Backup system, contingency procedures. • Very hard to properly design. From experience, the experimenta models tested were inadequate. I have touched on some of the issues previously and will leave it to the designers to expend. • Symbology, effects of latency • pitch attitudes, colors, eye strain, focal distance recognition, crosswinds • not familiar enough with HWD • Landing south at Boeing Field at night, I looked left and saw the bright city skyline obstacles, which became an amorphous blob confusing my mind. I then tried to dim the imagery down to reduce the effect, but then then it was too low to be useful for runway imagery. SVS is just not appropriate for head up or head worn. EVS is more appropriate. • Intended function, operational procedures, proper fit and alignment. • If the HWD were/were not configured for off boresight vision, this might confuse the cockpit situation. • Head motion • Head alignement, calibration and potential for specific HMD failures • Field of regard • Failure modes, reversion schemes, any required checks before operation or phase of flight. • Don't block the real world • Declutter, briteness control, calibration. • Care must be taken to not become overloaded /distracted by symbology. • brightness control, clutter, nav performance

For rollout, Expert respondents provided initial training recommendations similar to those previously mentioned for other phases of flight (Table 30). Again, limitations and crew coordination were emphasized for rollout. Specific to SVS on an HWD, the Experts also recommended training similar to other phases of flight, and also mentioned traffic identification and potential for critical elements in the external scene to be obscured (Table 31).

Table 30

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for a Rollout

What topics should be covered during initial training to learn to use a synthetic vision system for a rollout?
• Turn it off. SVS does not depict live threats on the runway and SVS will block your view. • The same as other phases of flight • System limitations. Crew coordination. Procedures. • System limitations and SOPs for use of SVS for rollout (crew coordination, call outs, etc.). • symbology, pitch attitudes, head movement, crosswinds • symbology needed for safe roll out • Which aspects may be more accurate than others (e.g., the source of the information), such as taxiway location / width, surface markings, signage. • Should be developped as type specific • same as the previous question • Capabilities and limitations of imagey and information displayed • interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level • Symbology, position accuracy and non-normals • Unless future operations requires SVS for landing, then the term "learn to use" is not appropriate (this applies to all previous phases of flight). Depending on the quality of the design, It could be used during specific non-normal situations affecting the guidance system in low visibility weather. This is not yet approved by the certification authorities. • correct brightness/contrast settings, failures management/ SOP callouts • Likely this is the most critical phase for CVS or SVS. How it is used to follow EFVS rules, what credits it grants for reduced minima, how to use it.... too much to add for this survey. • Symbology and cueing • Same as before • limitations of system design and how nav accuracy plays into display of screen • Repeat any RAAS/ROASS info on the HDD for non-HUD/HWD pilot and observer. • Proper runway marking recognition. • Limitations. Failures. • Limitations with SV vs. natural vision. • Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations, procedures for SVS fail during Low Visibility Operations • Learn about adjusting brightness/contrast.

What topics should be covered during initial training to learn to use a synthetic vision system for a rollout?
• Interpreting the synthetic vision information against the real surrounding terrain • Intended function, operational procedures, proper fit and alignment. • Identification of synthetic vs natural cues. • How compelling it is and not to be drawn into SVS as the complete picture. • ground hazards, vectors of vehicles etc • failure modes • DB consistency/validity (NOTAMS), potential for erroneous data: what takes priority is natural vision (i.e. do not "navigate" just based on SVS) • Clearing. Ability to confirm actual position vs synthetic position. • brightness control, clutter • Basic representation of runway, taxiway, and other relevant objects • Any inputs that may apply • accuracy of SVS

Note. Notice to Airmen (NOTAM); Runway Awareness and Advisory System (RAAS); Standard Operating Procedure (SOP)

Table 31

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for a Rollout, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for a rollout, if yes, please provide examples.
• Symbology size, format and color, head worn display structure, head positioning tracking • Similar to taxi and takeoff. • Poor fidelity • Limitations of display to provide information - colors, resolution, image fidelity • Scene flow and runway depiction realism • Limitations of display to provide information - colors, resolution, image fidelity • setup of hardware and calibration/ adjustment • Backup system, contingency procedures. • Very hard to properly design. From experience, the experimenta models tested were inadequate. I have touched on some of the issues previously and will leave it to the designers to expend. • Basic use, visual segment use permissibility, when to go around. • Care must be taken to not become overloaded /distracted by symbology. • Rapid head movement and the effect on visual system stability • potential for blocking the view of other ground traffic • not familiar enough with HWD • Intended function, operational procedures, proper fit and alignment.

Are there any special considerations if the synthetic vision is implemented on a head-worn display for a rollout, if yes, please provide examples.
• If the HWD were/were not configured for off boresight vision, this might confuse the cockpit situation. • HDD repeater management for PM • Field of regard • Don't block the real world • colors, eye strain, focal distance recognition, crosswinds • brightness control, clutter • A headworn blocks your view with SVS imagery no matter what direction you look.

For a missed approach, Expert respondents provided initial training recommendations like those previously mentioned for other phases of flight (Table 32). In addition, training recommendations included SVS guidance, depiction of a planned route, key aircraft parameters, and less reliance on synthetic data. Specific to SVS on an HWD, the Experts also recommended training similar to other phases of flight (Table 33).

Table 32

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for a Missed Approach

What topics should be covered during initial training to learn to use a synthetic vision system for a missed approach?
• Use the SVS as a backup to what you see outsideTerrain and obstacle identification. • symbology, pitch attitudes, vertigo, head movement, crosswinds • symbology needed for Missed • Should be developped as type specific • Capabilities and limitations of imagey and information displayed • interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level • System failures , alll • Basic use, visual segment use permissibility, when to go around. • Symbology, effects of latency • Basic training on differentiate real vs synthetic info • limitations and system design. What are limitations of navigational accuracy and how does that play into display • Realization that the presentation is conformal and may require different head movement as compared to HDD. • Primacy of instrument flight vs. SVS guidance importance. • PFD/MFD noramlly depict the planned route for M/A: this is associated to SVS/terrain. additional items to be "added" by the pilot are weather and traffic that may miss form PFDs/MFDs

What topics should be covered during initial training to learn to use a synthetic vision system for a missed approach?
• Location of key aircraft parameters from basic HUD and less reliance on synthetic data. • Limitations with the use of SV vs. natural vision or EVS. • Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations, procedures for SVS fail during Low Visibility Operations • limitations of database • Learn about adjusting brightness/contrast. • Intended function, operational procedures, proper fit and alignment. • Illusions, limitations. CFIT avoidance. • Good for obstacle and terrain avoidance. Potential use for course keeping during published missed approach • failure modes • Do not navigate with reference to the displayed terrain. • brightness control, clutter • Basic representation of obstacles • Any symbology that applies

Note. Multifunction Display (MFD)

Table 33

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for a Missed Approach, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for a missed approach, if yes, please provide examples.
• There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi. • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.). • Limitations of display to provide information - colors, resolution, image fidelity • setup of hardware and calibration/ adjustment • Backup system, contingency procedures. • Basic use, visual segment use permissibility, when to go around. • Symbology, effects of latency • Realization that the presentation is conformal and may require different head movement as compared to HDD. • Intended function, operational procedures, proper fit and alignment. • I guess if the HWD were/were not configured for off boresight vision, this might confuse the cockpit situation.

Are there any special considerations if the synthetic vision is implemented on a head-worn display for a missed approach, if yes, please provide examples.
• Fitment is critical. • Field of regard • fatigue (very often MA include many turns, which entail increased Nz); potential for distraction (close in weather phenomena) • Don't block the real world. Are you getting bored with having to read the same answer from me numerous times? • colors, eye strain, focal distance recognition, crosswinds • brightness control, clutter

For a balked landing, Expert respondents provided initial training recommendations similar to those previously mentioned for other phases of flight (Table 34). In addition, training recommendations included crew coordination and emphasis on a full brief beforehand, “particularly in a mountainous environment in which a VMC maneuver must be made because the IFR path/missed approach no longer applies.” Specific to SVSs on an HWD, the Experts also recommended training similar to other phases of flight, and additionally mentioned “the load factor at impact with ground [if unexpected/badly controlled] may cause HMD mounting set movement and loss of eye-sight alignment.” (Table 35).

Table 34

Open-ended Text Responses When Asked, What Topics Should be Covered During Initial Training to Learn to use a Synthetic Vision System for a Balked Landing

What topics should be covered during initial training to learn to use a synthetic vision system for a balked landing?
• The same as other phases of flight • Terrain and obstacle recognition. • symbology, pitch attitudes, vertigo, head movement, crosswinds • symbology needed • Should be developped as type specific • Capabilities and limitations of imagey and information displayed • interpretation of all symbology and recognition of degradation due to system failures or any other issue leading to less than required safety level • System failures , alll • Appreciation of the distances in a synthetic world • limitations of system design and how nav accuracy plays into display of screen • removal or changes in the PFD/MFD or HUD/HMD imagery in such a phase should not be encouraged: it may create potential for somatogravic illusion / spatial disorientation / pilot workload • Location of key aircraft parameters from basic HUD and less reliance on synthetic data. • Limitations.

What topics should be covered during initial training to learn to use a synthetic vision system for a balked landing?
• Limitations of the SVS, symboloy, alerts, procedures for SVS fail Engine Failure Operations, procedures for SVS fail during Low Visibility Operations • Learn about adjusting brightness/contrast. • It should not be used for landing. SVS obscures your natural view out the transparent windshield. • Intended function, operational procedures, proper fit and alignment. • Illusions, limitations, CFIT avoidance. • How compelling it is and not to be drawn into SVS as the complete picture. • failure modes • Energy state and cueing • Emphasize even with HWD/HUD that a full brief must be made beforehand - particularly in a mountainous environment in which a VMC maneuver must be made because the IFR path/missed approach no longer applies. • Don't just rely on SVS. • brightness control, clutter • Basic representation of runway and obstacles • Any input information/ symbols that would be seen by the pilot.

Note. Multifunction Display (MFD)

Table 35

Open-ended Text Responses When Asked, Are There any Special Considerations if the Synthetic Vision is Implemented on a Head-worn Display for Balked Landing, if yes, Please Provide Examples

Are there any special considerations if the synthetic vision is implemented on a head-worn display for balked landing, if yes, please provide examples.
• SVS blocks your view wherever you look. • There are considerations that need to be made for a head-worn or head up display. Realism, clutter, smoothness of motion, etc. This applies to all phases of flight. As one looks around this is more of a HWD training than an SVS training is where is forward when you are looking elsewhere? If you get disoriented during an upset/spin, can you find the symbology to get you to recvoer quickly and easily? This applies to all phases of flight other than Taxi. • Alignment with outside world may not be conformal with outside world (e.g. database may differ when it comes to things like shorelines, tree canopy heights, etc.). • Scene flow and runway depiction realism • Limitations of display to provide information - colors, resolution, image fidelity • setup of hardware and calibration/ adjustment • Backup system, contingency procedures. • Symbology, effects of latency • load factor at impact with ground (if unexpected/badly controlled) may cause HMD mounting set movement and loss of eye-sight alignement • Intended function, operational procedures, proper fit and alignment.

Are there any special considerations if the synthetic vision is implemented on a head-worn display for balked landing, if yes, please provide examples.
• Field of regard • Don't block the real world • colors, eye strain, focal distance recognition, crosswinds • brightness control, clutter

When Expert respondents were asked for training recommendations to distinguish synthetic imagery from natural vision for an SVS on an HWD, responses focused on simulator training and the use of SVS controls (on/off, brightness) as illustrated by one Expert's comments, "setting brightness and contrast levels appropriately LOW. Emphasizing that HUD and HWD are CONFORMAL devices and the real world is MEANT to be seen when visibility allows. #1 error I observe in pilots new to HUD - setting the brightness too high and channelizing on it". Other recommendations included scenario-specific training, such as transitioning from visual meteorological conditions (VMC) to IMC and IMC to VMC; and training in low visibility (Table 36).

Table 36

Open-ended Text Responses When Asked, What are Effective Training Methods to Learn how to Distinguish Synthetic Imagery from Natural Vision for Synthetic Vision System as Implemented on a Head-worn Display

What are effective training methods to learn how to distinguish synthetic imagery from natural vision for synthetic vision system as implemented on a head-worn display?
• Yes, particularly if the display has color capability. • Use of SVS controls (on/off, brightness). • Training with VMC conditions is an obvious need, but failures f the synthetic system can help to avoid overreliance • Training in VMC and IMC to VMC transition. • Training in low weather visibility • The imagery should be different enough by design to enable fast and intuitive differentiation. • teach what it can and cannot do... It is a tool, it helps the human and not a replacement for judgement and airmanship • Simulators, not necessary a FFS. • simulator training or similar devices with high fidelity • Simulator training • Simulator in in aircraft training to develop necessary skills. • Simulator • Shading, symbology, and method to de-clutter display of layers of imagery. • Setting brightness and contrast levels appropriately LOW. Emphasizing that HUD and HWD are CONFORMAL devices and the real world is MEANT to be seen when visibility allows. #1 error I observe in pilots new to HUD - setting the brightness too high and channelizing on it.

What are effective training methods to learn how to distinguish synthetic imagery from natural vision for synthetic vision system as implemented on a head-worn display?

- same as HUD. HWD physiological fit is key
- Same as before - distinct representation of represenation in the display. The pilot needs to be able to distinguish the different representations quickly, nearly instraontaniously.
- Proper hands-on training in a full motion simulator would suffice.
- Practice in sim or in real aircraft
- Not yet addressed. AED has failed to identify any.
- Not sure what is the intent of this question
- Not qualified to answer as I primarily use heads down system currently.
- Not proficient with HWD
- Not familiar enoug in HWD technology, however, for HUD having a SVS layer, use of the SVS declutter switch helps distinguishing synthetic imagery from natural vision.
- limitations of svs
- level of detail
- Is SVS on a HWD full color allowing for confusion with OTW visibility? I thought it was presented in monochromatic green colors, easily identified
- In essence the pilot needs to turn up or down the detail at any moment to check/ cross check the SVS
- If you can't distinguish between a monochrome synthetic and the real image, you have bigger problems.
- If the imagery is not obvious, modify the brightness/contrast of SVS and EVS to distinguish.
- If any map shift issues are possible/anticipated, this should be trained.
- I think it is a complex questions, because the answer will depend on the scenarios, day, night, dust, snow, storms(sand needs to be accounted as well)
- FFS training
- expose the crew to failure modes during realistic operaitonal scenarios (FFS?).As a minimum misalignement, frozen imagery, lack of DB precision, wrong horizon line alignment should be presented
- Don't worry. There is no way to confuse synthetic with natural. Synthetic vision is way different than natural vision. It's like a neon sign in Las Vegas compared to the beautiful natural scenery behind the glare.
- Don't block a pilot's eyes from the real world with synthetic info.
- Does that really need to be trained? Can one not tell what is computer generated and the real world when looking through the display? If the SVS is highly realistic, then there should be training on brightness setting and disengagement of the imagery.
- Do not know. Depends on the operation and aircraft
- Displays of illusions, limitations, examples of false or misleading information presented, or how to determine sensor failure, or reduction of capabilities.
- Demonstrate proficiency distinguishing synthetic image from observed cues.
- Color indicates natural vision.
- CBT, sim (static and full motion), etc.
- all the training levels should be utilized (manual, CBT, FTD, FFS).

What are effective training methods to learn how to distinguish synthetic imagery from natural vision for synthetic vision system as implemented on a head-worn display?
• Adjusting the HWD brightness downward so that it is not visible, and then back up so it is just visible over natural vision. • A thoroughly vetted upgrade program before being allowed to utilize system. • a pilot immediately knows the difference between SV and the real-world. This was an urban legend perpetuated by some technology neigh-sayers.

Note. Computer-Based Training (CBT); Out the Window (OTW)

4.3.5 Additional Feedback on Synthetic Vision Systems Implemented on a Head-worn Display

Other comments on SVSs implemented on an HWD are provided in Table 37. In general, comments indicated some discomfort with the use of SVS on HUD or HWD, concerns with navigation accuracy (e.g., GPS spoofing), and the importance of training.

Table 37

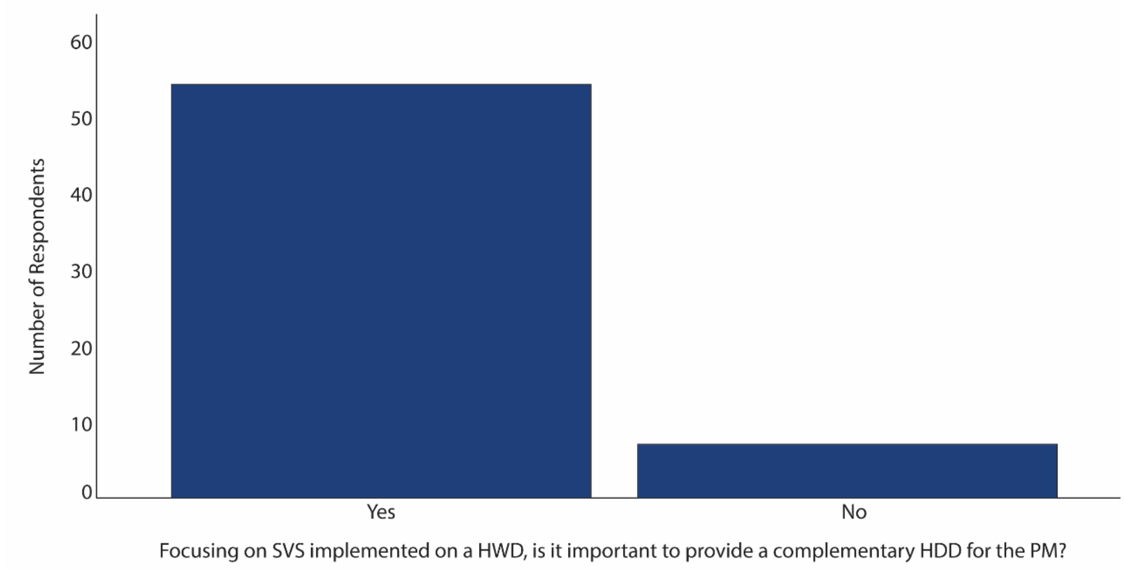
Open-ended Text Responses When Asked, Please Share any Additional Feedback on Topics Covered in This Section

Please share any additional feedback on topics covered in this section.
• The acceptability of the HWD is specific to the HWD model. • SVS is not appropriate for head up. • SVS could be used in place of real world view with many caveats. Issues in Navigations accuracy are primary concern (ie GPS spoof, GPS denial, etc) • SV is inherently more limited due to it's latency and static nature. Why not look harder at EVS? • Safety and operational considerations, although not always mutually exclusive, don't necessarily always align and should be considered separately. • Must be used to augment the pilot, not overwhelm or distract the pilot • For any sort of SVS or HWD, you must ensure the training and human factors are emphasized. Like auto pilot, pilots rely on technology and are uncomfortable when required to actually fly the airplane as they normally had. Recognizing when the system has failed and quickly transitioning to "good old fashioned pilot stuff" is critical to safety

4.3.6 Synthetic Vision System Pilot Monitoring Display

When asked if it is important to provide an HDD for the Pilot Monitoring (PM) when a SVS is presented to Pilot Flying (PF) on an HWD, 88.5% (n = 54) of the 61 Experts who responded to the question indicated "Yes", it is important, and 11.5% (n = 7) indicated "No", it is not important to provide an HDD for the PM (Figure 8).

Figure 8
Is it Important to Provide a Complementary Head-down Display for the Pilot Monitoring



Common themes among the open-ended responses for those who thought an HDD with SVS should be provided for the PM included an increase in PM situational awareness and a more accurate shared mental model between PF and PM (Table 38). Those who responded "No" were presented with a follow-up question asking if they had any concerns with the PF and PM having different information presented to the pilots; 3 of the 7 Experts indicated they were concerned about different information being presented to the different pilot roles.

Table 38
Open-ended Text Responses When Asked, What are the Benefits for a Complementary Head-down Display for the Pilot Monitoring

What are the benefits for a complementary head-down display for the pilot monitoring?
• You have both pilots aware of what is going • We can't rely on the helmet always working. Likewise, it may help to provide a secondary source of info if the pilot starts to doubt the helmet info. It will also provide info for observers. • Validate the PF's actions when in CATIII situations. • Use as a back-up in the event of a failure. • Training for PM (First Officer) so that they see the environment and at least understand utilization prior to upgrade to PF (Captain). • To have the ability to confirm the PF's determination of SVS contact with the airfield environment • This would allow the PM an opportunity to better see the flight path! • They are kept in the loop of what flying pilot sees. • The PM is much more likely to recognize abnormalities outside of the PF's field of view (i.e.: engine instruments, malfunction annunciations).

What are the benefits for a complementary head-down display for the pilot monitoring?

- The HDD display provided feedback to the pilot in color and as of today the HWD are monochromatic. It would be great addition to safety, but not required if integrating with older aircraft that do not posses SVS on HDD.
- SVS is best viewed on a head-down display in the first place. Pilot monitoring view is required for many operational credit conditions of Enhanced Vision Systems.
- SVGS could occlude the out the window view and be distracting. Head down would allow pilot to see OTW unobstructed.
- Recognizing that the HWD offers a unique perspective, the design of a complementary head-down display is not simply a replication of the PF view. Done well it will provide enhanced safety via improved crew coordination, independent verification and enhanced situational awareness of the pilot monitoring.
- PM in the loop. Relieves PM from mentally recreating the visual presentation.
- PM confirmation of scene to ensure both pilots are "seeing" the same things prior to going below IAP minima.
- Pilot monitoring primary function is to monitor and call deviations. Both pilots must have access to the same information in order to be on the same page
- More awareness for the PM and CRM
- Monitoring misbehavior of SVS that is typically a DAL C system.
- Monitoring capability is required for two-crew operations. It does not need to be a HWD application however.
- Keep the PM in the loop of the flight path and anh other annunciations that may be displayed to the PF through his/her HWD.
- Increased SA. Our airline is increasing the responsibility of a PM to that of an instructor.
- In case of failures of the head-worn unit, you would want seamless transition to the head-down display to alleviate startle effects when information is suddenly removed from the pilot. It will decrease the time delay that the pilot will have to recover from the loss of information on the head-worn display.
- except for Part 91 single pilot ops, PM needs to be in the loop during EFVS ops, crosschecking and confirming
- dual source of information with independent paths
- Current issues I’ve observed with HWD are visual system interruption due to disturbance of the equipment when the Pilot moves their head (ie accomplishment of NNCs). In the event of a system failure on a single side, repeating data seems necessary for flight safety.
- Cross check, MMEL, redundancy.
- Cross check and monitoring purposes, especially if you're going to allow for approach credit below standard CAT 1
- Continuous situational awareness for the PM of aircraft path management, verification of expected PF actions, possibility of overlaying other information that may not be the focus of PF but can be valid for the PM situational awareness .
- Consistency check Monitoring of possible SVS related failures
- Confirmation of what is occuring on the flight deck, enhance CRM and Risk Mgmt. Will likely help ID hazards for HEMS/HAA and military usage of things like DVE are safety enhancements that cost less than a life or an aircraft
- Confirmation / verification of info in the HWD. Also for a backup and quick transition if a failure occurs in the HWD.

What are the benefits for a complementary head-down display for the pilot monitoring?
• Complementary HDD for the PM is normal for a 2 pilot aircraft. For HWD, I think it would provide situational awareness and monitoring capability for the PM. • Check and balance for accuracy. • Both pilots are using the same information. • Backup/redundant system in event of failure or disorientation. • Backup mode or or for pilot not flying • Backing up the same presentation when system degraded still allowing some credits/benefits like situation awareness. • Back-up screen in case HWD goes down and does not function. Reducdency of displays provides the opportunity for Cat II and III systems. • back up, redundancy, depending on airplane level function availability, safety assessment • Awareness of what PF is seeing, enhancing raw data x-check, possible ability to notice SV and raw data asynchrony. • As has been discovered in other HUD systems, the pilot flying cannot properly monitor what the pilot flying is using to make flight decisions. A secondary HUD for the PM should be mandatory, or at least a display of the EVS imagery. • As a safety backup, the PM should have as much of the picture as possible. • As a redundant system • Ability to meaningly provide backup and crosscheck of PF. • A shared mental model of the aircraft state and flight path between the two pilots. • A PM monitoring head-down SVS would be able to monitor for database inaccuracies while the PF is engaged with flying. This could lead to faster detection of database inaccuracies and reduced risk of CFIT accidents than if there is no PM SVS repeater. • 1. PM awareness ("staying in the loop of PF decisions"); 2. monitoring of SVS potential failures and stabilization of the approach, if this is anyhow based on SVS information.

Note. Design Assurance Level (DAL); Master Minimum Equipment List (MMEL); Non-normal Checklist (NNC); Out the Window (OTW)

4.3.7 Synthetic Vision Systems for Operations Under Visual Flight Rules

When asked if benefits exist for using SVS for Visual Flight Rules (VFR) operations, 90.0% (n = 54) of the 60 Experts who responded to the question indicated “Yes” (Figure 9), and 10.0% (n = 6) indicated “No”. Their comments ranged across topics that include benefits for VFR at night; symbology to improve situational awareness; and terrain and obstacle awareness (Table 39).

Figure 9
Are There any Safety and/or Operational Benefits to a Synthetic Vision System for Visual Flight Rules Operations

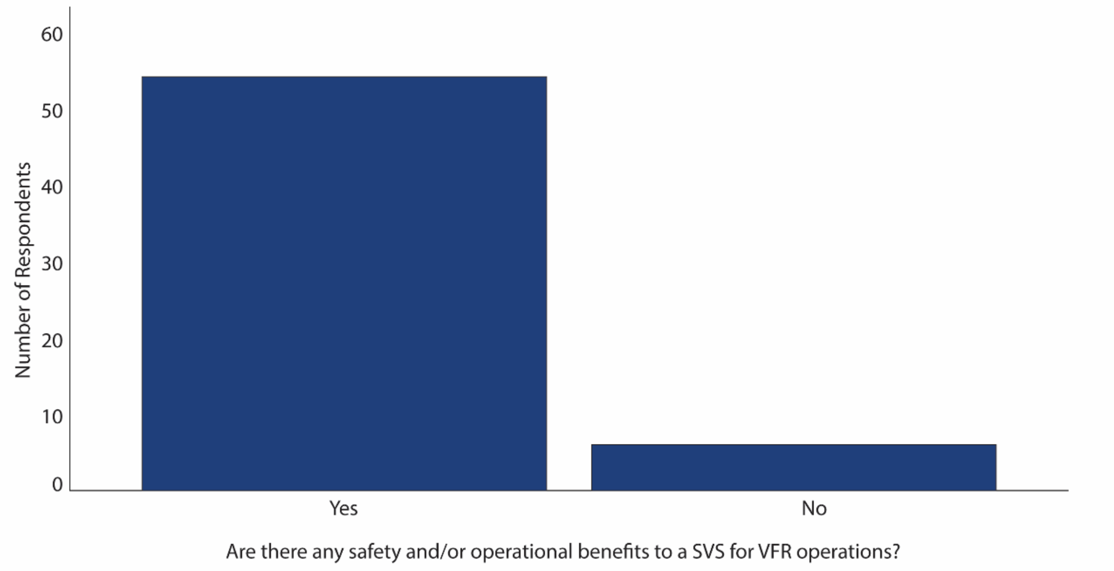


Table 39
Open-ended Text Responses When Asked, What are the Benefits of a Synthetic Vision System for Visual Flight Rules Operations

What are the benefits of a synthetic vision system for VFR operations?
• With reduced VFR visibility it can enhance the upcoming terrain and obstacles not yet visible and provide ample time to adjust course or altitude if necessary.
• VFR flights requires only 3 miles of flight visibility (less for special VFR). Many pilots get in trouble flying VFR in marginal flight visibility, not being the best judge of what 3 miles represent. SVS would help in these cases. If the visibility is unlimited, then a SVS has very little use.
• Understanding the orientation of the airport when operating at an unfamiliar area
• The additional information presented in the display provides situational awareness. such as the runway remaining for take-off and landing.
• Terrain awareness
• Terrain and obstacle projection. I'd enjoy seeing traffic from ADS-B TIS in a HWD, too.
• terrain and obstacle awareness still a benefit even in VMC conditions
• SVS is an aid for the pilot to keep awareness of runway position in relation to flight path when flying visual circuit approaches.
• SVS could improve awareness of terrain during VFR flight at night.
• Specifically helicopter: flying into off airport areas would highly benefit operations.
• situational awareness, operational efficiency
• Situational awareness, visualizing traffic, better visibility of warnings, localization of airport, highyway in the sky for emergency landing

What are the benefits of a synthetic vision system for VFR operations?

- Situational awareness and spatial awareness relative to terrain, airport and runway environment, and hazards such as obstacles and other aircraft.
- Situational awareness (terrrain/obstacles), presentation of PFD when looking out (self separation from traffic and terrain), terrain awaerenss during VFR "on top" operations, support for navigation (better awarenss of specific landmarks/terrain related reporting points, etc.)
- Situational awareness
- Situation awareness,
- Situation awareness of terrain during night and situation aware of flight plan depiction during all times.
- see NASA research papers. See CAST ASA[13] reports
- see and avoid, better UAS deconfliction, possible bird/wildlife mitigation,
- Same benefits as previously stated - awareness of terrain etc. This can still provide that awareness even in VFR operations.
- reduced pilot workload and situational awareness
- Provides graphical indication of terrain, obstacles, airports, extended centerlines, and also bearing and distance info for any of the above in a heads up display.
- Obstacles encountered in marginal VFR such as haze/smoke/smog. (Think LA)
- obstacles (man made, terrain) identification and avoidance.
- Obstacle locations and airport/runway orientations
- Obstacle identification, airfield identification, runway identification, taxi, position confirmation
- Obstacle awareness like towers.
- Night, VMC or in visibility conditions that do not meet IMC definition, think helicopter air ambulance operations at night in rural areas in VMC, high overcast, moonless conditions with lack of distinct visual horizon.
- night VFR (both ground reference as well as cloud avoidance), day traffic avoidance when ADS-B in integrated.
- Night operations. Especially if it will help pilots pick out landing fields during partial or complete power loss.
- more awareness, but not to be used to avoid obstacles.
- Low altitude VFR flying could benefit from SVS for obstacle clearance
- Locating airport and runway centerline
- Increased situational awareness
- In VFR, only at night. No real use in the day, unless navigation is part of the SVS conops.
- Improved awareness
- Improve situational awareness.
- If on a HWD it may assist the pilot with obstacle avoidance.
- Identifying correct runway. Obstacles, terrain avoidance.

[13] Commercial Aviation Safety Team, (2014). Airplane State Awareness Joint Safety Analysis Team: Final Report Analysis and Results. https://www.cast-safety.org/pdf/JSAT-ASA_FinalReport_June2014.pdf

What are the benefits of a synthetic vision system for VFR operations?
• identification of visual references on the ground; identifying other traffic; seeing through marginal weather or VFR on TOP
• Enhanced situational awareness during periods of reduced visibility/night operations.
• During VFR ops, symbology like extended centerline, airports flags etc are very beneficial to SA especially in urban areas where airport may be hard to spot.
• Data validation
• Confirmation of existing visual information
• CFIT at night
• Better awareness
• Awareness of obstacles and flight data, ability to adjust to inadvertent IMC.
• Avoidance of illusions such as black hole effect
• Assuming traffic is a part of the display system, traffic and general terrain awareness, particularly at night.
• Added situational awareness
• A synthetic vision can depict obstacles and traffic that might be too far away to be easily spotted visually to help VFR pilots maintain a safe distance and deconflict from other airspace users.

Note. Uncrewed Aircraft System (UAS)

When asked to identify safety and/or operational benefits of an SVS for VFR operations dependent on the display type, 46.7% (*n* = 28) of the 60 Experts who answered said HWD, followed by HUD (35%; *n* = 21), and then HDD (18.3%; *n* = 11; Table 40).

Table 40
Safety and/or Operational Benefits of a Synthetic Vision System for Visual Flight Rules Operations: Most Beneficial Display Type

Display	Count (n)	Percentage (%)
Head-worn Display (HWD)	28	46.7
Head-up Display (HUD)	21	35.0
Head-down Display (HDD)	11	18.3
Total	60	100

Note. *N* = 60. Respondents were asked to select all that apply.

4.3.8 Synthetic Vision Systems with Pathway Guidance Symbology

When asked if there is a benefit to pathway guidance symbology on SVSs, 81.7% (*n* = 49) of the 60 Experts who responded indicated “Yes”, and 18.3% (*n* = 11) indicated “No”. When asked if the benefits of pathway guidance are display-dependent, 58 Experts responded. Of those 37 Experts who indicated benefits are display-dependent, respondents generally indicated that the symbology would be most beneficial if displayed on either a HUD or HWD (56.8%, *n* = 21, each), and 37.8% indicated HDD as the most beneficial (*n* = 14; Table 41). Respondents were also asked about the effect of pathway guidance symbology on pilot workload. Of the 60 respondents who answered, 71.7% (*n* = 43) indicated it would decrease workload; 15.0% (*n* =

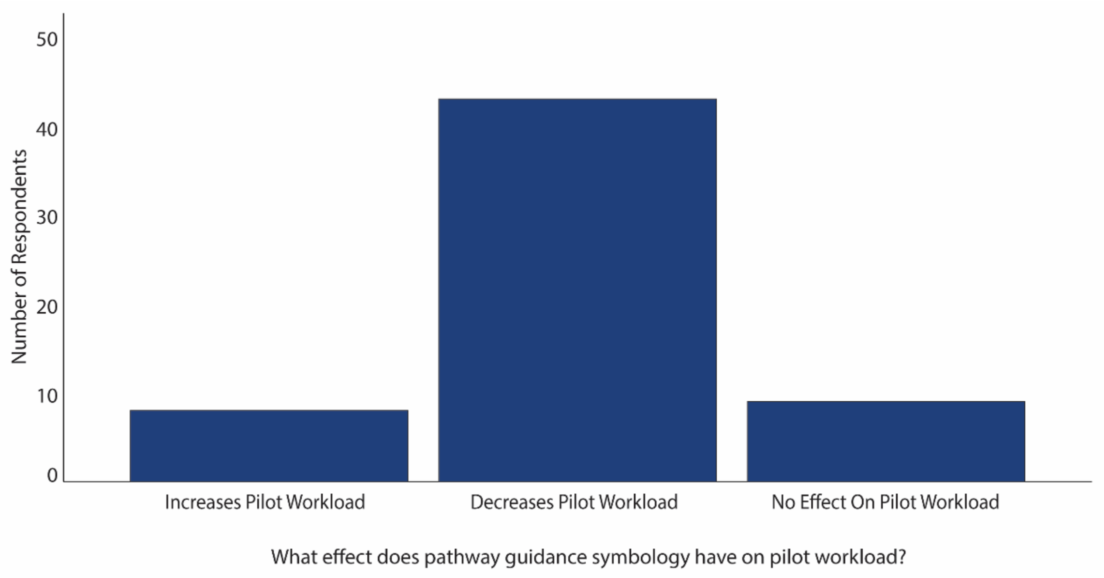
9) thought it would have no effect on workload; 13.3% (*n* = 8) reported that it would increase workload (Figure 10). Responses to an open-field question ranged topics, including higher adherence to flight paths and better situational awareness with one Expert noting that the type of guidance is important, “A HITS system can lead the pilot into terrain if the pilot is unaware of how the system operates. How is the FPM "quickened"? How hard is it for the pilot to maintain HITS "center"? For approaches, does HITS mimic LPV or LP[14] geometries? How much will pilots channelize their attention on HITS path adherence and what are the effects on x-check? There are too many variables to say "Yes" or "No"”. (Table 42).

Table 41
Most Beneficial Display Type for Pathway Guidance Symbology

Display	Count (n)	Percentage (%)
Head-worn Display (HWD)	21	35.0
Head-up Display (HUD)	21	35.0
Head-down Display (HDD)	14	23.3

Note. *N* = 60. Respondents were asked to select all that apply.

Figure 10
Effect of Pathway Guidance Symbology on Pilot Workload



[14] Localizer Performance (LP); Localizer Performance with Vertical Guidance (LPV)

Table 42

Open-ended Text Responses When Asked, What are the Benefits for Pathway Guidance Symbology for a Synthetic Vision System (for Example, Tunnel Symbology or Pathway-in-the-sky Symbology)

What are the benefits for pathway guidance symbology for a synthetic vision system (for example, tunnel symbology or pathway-in-the-sky symbology)?
• Tunnel/pathway-in-the-sky symbology has some benefits, but also some drawbacks. It has been shown to marginally improve flightpath tracking, but can increase the risk of attentional tunneling. This in turn may increase the risk of CFIT accidents. • Today´s Vertical and Lateral guidance, being ILS or GPS based, requires pilots to build a mental model of the position of the airplane in relation to lateral and vertical path. Pathway symbology is less cognitive demanding and more straight forward interpretation. • Taxi and runway thresholds, other traffic, etc. • Spatial awareness of approach path • Situational awareness, safety case • Situational awareness and precise flight path. • Simplified cues to reduce workload • Shows you where you are going • see NASA reports... mostly for turn anticipation, pilot awareness of RNP-type arrivals • Said yes to get this box to pop up because this is not a binary answer. Depends on the system and how it is implemented. A HITS system can lead the pilot into terrain if the pilot is unaware of how the system operates. How is the FPM "quickened"? How hard is it for the pilot to maintain HITS "center"? For approaches, does HITS mimic LPV or LP geometries? How much will pilots channelize their attention on HITS path adherence and what are the effects on x-check? There are too many variables to say "Yes" or "No" • Real time flight path information grouped in one single cue • Proper flight path control • Precise flight paths • Possible enhanced safety from pathway guidance. Depends on the level of experience and or skill or the pilot involved. • Positional awareness, altitude/airspeed restrictions, • Navigation validation • navigation guidance and increased situational awareness • More precise location by time. The specific design of this would need to be considered and evaluated to be shown to be beneficial as compared to no pathway guidance symbology. • Minor improvement in SA, maybe better flight technical error for manual flight. • maybe easier to follow for VFR pilots • Keeping on a lateral and vertical track with a high amount of precision. • it would help with unstable approaches • It would confirm navigation path currently on if database was correct and current. • It simplifies flying and will help pilots visualize where they should be flying. However, that's going to be garbage in / garbage out if the system is programed incorrectly • Intuitive flight guidance

What are the benefits for pathway guidance symbology for a synthetic vision system (for example, tunnel symbology or pathway-in-the-sky symbology)?
• In emergency situations • Improved flight path management. • Improved awareness • I like extended runway centerlines. Other info might be too cluttered. • I have no experience with this function. • Hwy-in-the-sky has been used before. I believe this type of symbology aid the "newer" pilots with approaches to the runway. Unsure, if its a great benefit for more experience pilot and may be consider clutter. • Help guide the pilot. • Guidance and prediction of aircraft capabilities. • General non-precision guidance • Ensuring you are in the correct position and on course • Easy to monitor the desired/calculated 3D path in one view. • Easily focus on the approach • easily displayed on HDD (low cost), reduced CFIT during descent/approach/landing • confirm the correct flight path trajectory and accuracy of the touchdown zone • compliments pitch and power settings, able to provide a whole picture to crew... • Can help notify / inform pilot of planned changes to the vertical and lateral flight plan. Can help with energy management. • Better control of the trajectory • Being able to visually confirm mental model of flight plan path in the sky. • As a minimum situational awareness could be envisaged. However, it should be noted that "highway in the sky" symbols are not adequate for precise IFR path management (e.g. during IFR approahces). The usual FD symbols are preferrable • Another way to show energy state when head it outside the cockpit.

Note. Localizer Performance (LP); Localizer Performance with Vertical Guidance (LPVG)

4.3.9 Synthetic Vision Systems During Non-normal or Emergency Situations

The Expert respondents were asked about the benefits of using SV during non-normal or emergency situations. Of the 59 Expert responders who provided a response to the question, 71.2% (*n* = 42) indicated SV would be a beneficial tool in these situations. More specifically, when asked whether the benefits are dependent on display type, 61.0% (*n* = 36) indicated that the benefits are display dependent. Of those 36 Experts who believe SVS benefits are display dependent, 66.7% (*n* = 24) selected HUD over the other display types for presenting symbology, 44.4% (*n* = 16) selected HWD, and 41.7% (*n* = 15) selected HDD (Table 43). Experts' comments commonly cited increased situational awareness of an airport or terrain when a pilot is already in a heightened workload state due to an emergency situation (Table 44).

Table 43

Most Beneficial Display Type for Synthetic Vision During Non-normal or Emergency Situations

Non-normal or Emergency Situation	Benefit for Display Type						
	HDD (n)	HDD (%)	HUD (n)	HUD (%)	HWD (n)	HWD (%)	Total
CFIT	12	18.2	27	40.9	27	40.9	66
General Non-normal or Emergency	15	27.3	24	43.6	16	29.1	55
Runway Incursion	10	18.2	21	38.2	24	43.6	55
Engine Failure	8	15.7	24	47.1	19	37.3	51
Runway Excursion	4	8.5	23	48.9	20	42.6	47
Prevent or Recover from a Aircraft Upset	8	17.4	19	41.3	19	41.3	46
Total	57		138		125		320

Note. *N* = 60. Respondents were asked to select all that apply.

Table 44

Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision for Abnormal, Non-normal, or Emergency Situations

What are the benefits of synthetic vision for abnormal, non-normal, or emergency situations?
• Workload alleviation, situational awareness • Traffic, reduced visability and taxi centerline. • To directly answer this question: Yes during MAPP where terrain on the MAP path is an issue. NOTE: However, the previous question regarding pathway guidance symbology (which could be a flight director rather than a HITS) and effect on pilot workload is pretty broad. It is dependent on the operation, the characteristics of the HITS, the amount of quickening for a FPM or "follow-me" symbol used, etc. Pilot workload based on what? Keeping the FPV and aircraft symbol in the middle of the path? Effect on x-check? etc. • This symbology could be useful to increase SA in some specific emergency conditions e.g. path for emergency descent or safe escape for RNP-AR or OEI VPR escape routes afer T/O or G/A. Note: to achieve such goal the path guidance should be programmable to adapt to the specific situation (e.g. Emergency descent turn direction and track change depends on local operational regulations, etc.) • terrain avoidance; emergency landings off runways or ditching; selection of emergency landing runway to be used, based on distance, glide path, wind, runway length, obstacles, etc • Spatial awareness • Situational awareness and precise flightpath • Same as stated previously

What are the benefits of synthetic vision for abnormal, non-normal, or emergency situations?

- Reduced flight path workload enhances concentration and decision making during non-normals or emergencies.
- Reduce workload. Improve SA
- quick visual guidance of path
- Provide flight path guidance
- Potential benefits in mountainous terrain preventing CFIT during emergency situations.
- PathWay will benefit DrifDown, Initial Climb with One Engine Out, aiding pilots to maintain correct flight path for obstacle clearances purposes, help mitigate level busts during go around.
- Pathway guidance may be beneficial on a HDD during a missed approach or terrain escape maneuver. On a HUD or HWD, FD/FPV guidance may be more beneficial than pathway guidance. The visual clutter from pathway guidance may hinder visibility of obstacles during a terrain escape maneuver.
- Particularly in single engine aircraft at night, for immediate returns to an airport, or identifying suitable emergency landing areas.
- Obstacles are clearly displayed in the head worn display which consolidates information.
- navigation to airport, clearing of obstructions
- Low workload for the pilot flying
- It will benefit in emergency situations if it delivers vital deciding factors accurately and without fail.
- It could assist pilot with best approach angle in case of engine failure, if automatically activated and integrated with the aircraft.
- Increased situation awareness of terrain and obstacles, say, during a go around.
- incapacitated pilot
- Improved awareness and reduced workload
- If you could predict the aircraft performance, and an engine or performance emergency occurred, the system could actively determine if terrain/obstacle clearance could be maintained.
- Highway in the sky to landing, airport localization, pilot disorientation
- Help the pilot visualize emergency descents and faster recognition of path deviations.
- Having a path to follow would help in many situations. Driftdown, single engine ops...
- Get into a more secure situation quicker by following the head up and not look at info on the PDUs
- For certain operations (e.g., especially powered-lift or rotorcraft), pathway guidance symbology could be used to show plausible landing areas (this would require other functionality (databases, sensors) to inform the pathway).
- flight path in a all engine out condition and flight path guidance during approach to control touch down point
- Energy awareness for low energy conditions (such as single engine driftdown)
- Easier to monitor than a traditional flight director.
- decrease navigation workload (navigate is enhanced by the highway in the sky) leaving more spare capacity to the pilots to tackle the abnormal
- Can provide more focus on emergency when only have to quickly glance to ensure you're in the box.

What are the benefits of synthetic vision for abnormal, non-normal, or emergency situations?
• Better situational awareness.
• best glide ratio, all night flying
• auto pilot failure is a perfect example, much easier to stay on course with pathways
• Ability of the PF to visually perceive cues and PM changes to navigation

Note. Primary Display Unit (PDU)

Sixty (85.7%) Experts responded with their preference for display type for Runway Incursions (Figure 11). The Experts indicated that SVS may specifically help prevent Runway Incursions 83.3% (*n* = 50); a smaller number of Experts indicated that they did not think SVS would help prevent Runway Incursions 16.7% (*n* = 10). Comments received from the Experts generally indicated they thought SVS coupled with Automatic Dependent Surveillance–Broadcast (ADS-B) data may help prevent Runway Incursions; however, comments also noted ADS-B information would not provide assistance with Incursion situations involving an airport maintenance vehicle (Table 45). Thirty-two Experts, 53.3% of respondents, indicated they thought the benefit would depend on the display type in which the symbology is presented, with 46.7% (*n* = 28) indicating the display type would not make a difference.

Figure 11
Do you see a Concept Where a Synthetic Vision System may Help Prevent a Runway Incursion

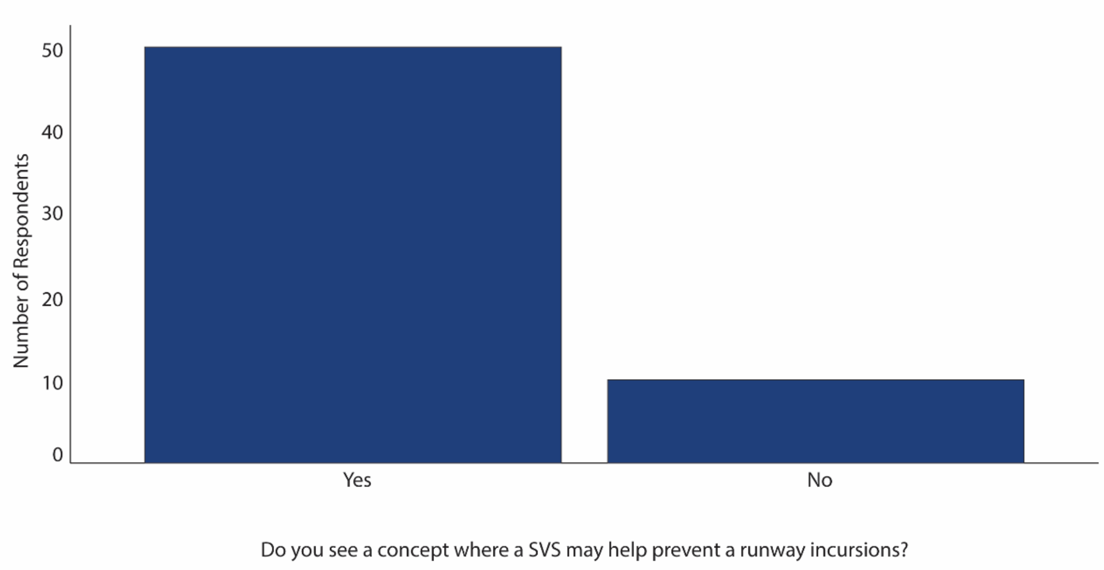


Table 45

Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision to Help Prevent Runway Incursions (for Example, the Incorrect Presence of an Aircraft, Vehicle, or Person on the Protected Area of a Surface Designated for the Landing and Takeoff of Aircraft)

What are the benefits of synthetic vision to help prevent runway incursions (for example, the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft)?
• with ADSB or with EVS image • Using adsb in embedded into the svs as well as AI transcripting ATC messages into displayed objects • Used displayed information more clear and accurated. • Traffic awareness overlay • This would have to be investigated to avoid excessive clutter, but ADS-Bin target indication on SVS (say, in SURF mode) would be useful if adequate symbology can be worked out. • Taxi during low visibility operations. • Synthetic vision systems can more prominently display information such as runway and taxiway identification markers, hold short markings, etc. to help pilots better understand where they are located and what is around them. With a head-mounted system that tracks head movement, a pilot can also get a better understanding of what is next to the aircraft prior to making any turns, whereas a traditional HUD or head-down display might only provide high quality information about what is directly in front of the aircraft. • Synthetic vision does not show actual hazards, it shows databased representations of what was present when surveyed for the database. If you are talking about enhanced vision, or an ADSB target added to a head-up display, then that would be a benefit, but it is not SVS. SVS only adds clutter and misleading representation to a heads up. display (except for the benefit or airport locator and extended centerline) • SVS could have virtual stop bars and restricted/prohibited areas symbols • Situational awareness, safety case • situational awareness would substantially increase • Situational awareness in all phases of flight especially during landing, take-off and taxing in low visibility situations • Situational awareness and own ship moving map view. • situational awareness • Situational and spatial awareness of runway environment, terrain, obstacles, and other aircraft. • see NASA T-NASA and RIPS research. Awareness of ownship position and maneuvering areas greatly reduce surface operations errors and runway incursions. (Much of this is now part of moving maps) • Same as the question implies • Runway crossings and Hot Spots can be highlighted in a HUD or HWD. Also I'd like to see our industry pursue COLOR and adding ADS-B TIS info into our cockpits - all displays, but particularly the HUD/HWD. • Putting up pathway markers with directional arrows, showing virtual "fences" to help with runway incursions and wrong taxiways • Placing ADS-B In traffic data on the HUD can avoid incursions, as well as provide a display for alerting if a traffic alerting algorithm were available.

What are the benefits of synthetic vision to help prevent runway incursions (for example, the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft)?

- only would be a benefit if everything that needed to be detected is transmitting to be graphically depicted on a synthetic vision display. Otherwise SVS will not help with runway incursions and collisions with a foreign object. SVS can help ownship determine whether they are taxiing across a runway.
- Only if combined with enhanced vision system.
- None unless coupled with CPDLC and displayed taxi instructions.
- Moving map of the airfield providing taxiway/runway locations and references
- Mismatch between visible objects seen between EVS and SVS.
- Maybe - only if the SVS integrated real-time geolocation data from surrounding vehicles. I don't see how SVS could feasibly help prevent runway incursion if there is a person on the runway.
- MArkings such as "hot areas" displayed on top of synthetic terrain. Additionally, ADS-B information overlaid onto display is helpful
- LVTO/LVO operations: view of taxyways / intersections / runways when on ground would enhance SA and possibly prevent/help correcting crew or ATC errors. Clarification for the next question: the most appropriate display for SVS depends on the phase of flight. Indeed a "bird's view" 3-D style presentation of the airport layout and a/c PP is only suitable for Head down displays and at low speed (e.g. taxiing towards the runway or towards the apron). For high speed conditions HUD or HMD may be more adequate for SVS the presentation of conformal imagery of the airport and taxiways/runways/intersections/crossings/hot spots. Similarly, right after landing, a good SA of the taxiway to be taken and subsequent taxi route may be helpful to avoid crossing runways or entering "hot spots" at high speed.
- It could prevent a catastrophic event
- It can help with highlighting runway surfaces.
- It can depict the entry points to runways
- increased warning time to hazard, allows real time updates to crew, can color code the threat and suggest action to remedy
- Increased awareness of airport configuration
- In low vis you can use the synthetic image to enhance and confirm what you think you are seeing out the window.
- Improved awareness
- If the system showed an incursion and subsequently rejected landing based on performance algorithms, aside from possible erroneous indications I can see it being a benefit
- If the system is able to recognize a hazard and notify the pilots early the system would be beneficial.
- If ADS-B IN integrated with SVS, it could provide the visual alerting to the pilot if runway was occupied.
- Especially in circling approaches
- Enhancing situational awareness
- Enhanced situational awareness.
- Better situational awareness.
- better SA in taxi, may help a pilot from getting "lost".

What are the benefits of synthetic vision to help prevent runway incursions (for example, the incorrect presence of an aircraft, vehicle, or person on the protected area of a surface designated for the landing and takeoff of aircraft)?
• any transponder equipped item could be displayed on the SVS (Garmin already shows the TA or RA on the HUD enhancing the safety) • Allows pilot to remain heads up more often. • Aircraft and vehicles on tower controlled areas can use transponder/ADS-B technology to show position on the airfield. • Again, dependent on the technologies involved. SV in and of itself will not. However, coupled with real-time position information of other aircraft and taxiway/runway relative position, yes. This is all dependent on compatible systems, standardized requirements for displays and reliabilities of the systems. Misleading information, particularly not showing an incursion when there is one, could result in potential catastrophic outcome. • ADS-B In information shown on the SVS (in addition to current top-down airport moving maps that show ADS-B In information).

Note. Artificial Intelligence (AI); Air Traffic Control (ATC); Controller-pilot Data Link Communication (CPDLC); Resolution Advisory (RA); Traffic Advisory (TA).

Fifty-nine Experts responded to the question regarding whether SVS may help prevent runway excursions. Of those 59 Expert respondents, 74.6% (*n* = 44) indicated that SVS may help prevent Runway Excursions. Thirty Experts (50.8%) believed SVS benefits would be dependent on the type of display. Of those 30 participants, HUD was the most-frequently selected display type (76.7%; *n* = 23; Table 43). Fifteen Experts (25.4%) indicated that SVS would not be beneficial for Runway Excursions (Figure 12). In general, Experts expressed in their comments that SVS may help with a pilot's situation awareness, as they may better understand runway and ownship position on the runway (Table 46). Certain symbology elements were identified as beneficial, including a representation of flight path relative to desired touchdown point, runway remaining, runway boundaries, and/or deceleration rate cues.

Figure 12
Do you see a Concept Where a Synthetic Vision System may Help Prevent a Runway Excursion

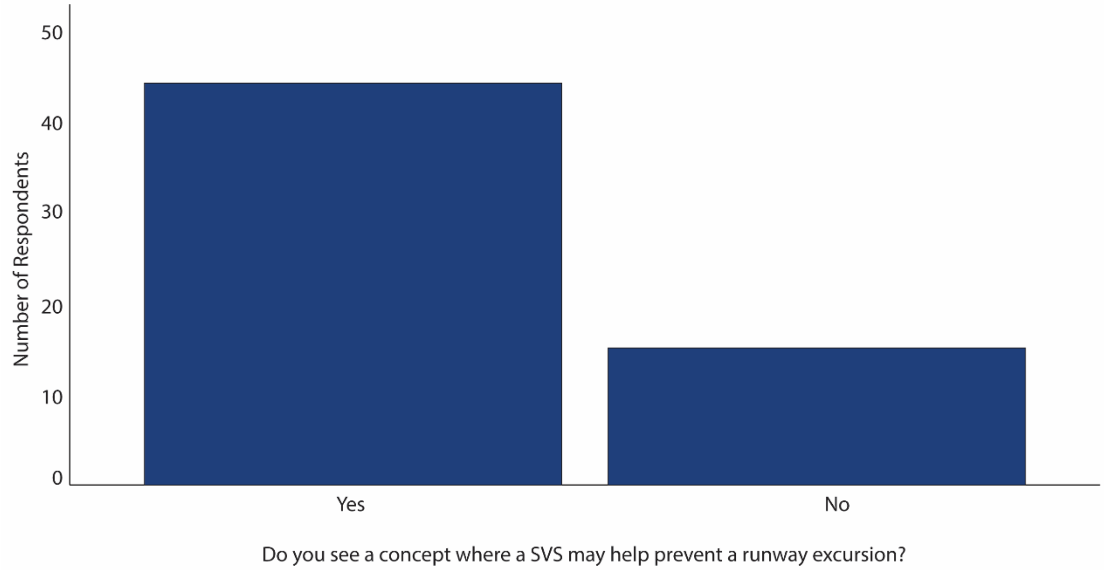


Table 46
Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision to Help Prevent Runway Excursions (for Example, a Veer off or Overrun From the Runway Surface)

What are the benefits of synthetic vision to help prevent runway excursions (for example, a veer off or overrun from the runway surface)?
• Gives the pilot a better sense of position in reduced visibility environments. • warn the flightcrew about obstacles • In low visibility it may help • Unstable approach leading to a runway overrun • Low visibility operation. • SVS may help prevent runway excursion during rollout, taxi, and takeoff in CAT III weather conditions. • RAS and ROAAS cueing • Can be more effective in certain types of weather that enhanced vision is not. • Landing and rollout in low visibility conditions. • low vis takeoff • can identify ADSB traffic as well added bill boards or runway edge markers • Only a representation of flight path relative to desired touchdown point, runway remaining, and/or deceleration rate are beneficial. These are not synthetic vision, and the more widely recognized elements of synthetic vision such as representation of terrain, runway, and obstacles would actually detract from those key elements (flight path, touchdown point, runway remaining, deceleration rate). • help visualize path stabilization, maintaining path, touchdown point. With proper symbology, maintain energy.

What are the benefits of synthetic vision to help prevent runway excursions (for example, a veer off or overrun from the runway surface)?
• For veer offs a "velocity vector" on the ground would help show where the aircraft will be in the future • Situational and spatial awareness of runway environment, obstacles, and other aircraft during low visibility and night. • Distance remaining info increases situational awareness and lessens pilot reaction time. Crowned runways, reduced visibility, etc • SVS system is essential during LVPs • additional data such as remaining LDA and runway lateral limits could compose real/virtual images and alerts to keep runway centerline and/or increase braking performance. • just like a car HUD, able to used words to command an action or even integrate into the brake system • Mostly with excursions off the end of the runway - and this begins earlier with a stabilized approach. Excursions off the SIDE of runways are not (IMO) due to lack of visual guidance that a HWD or HUD would assist with. • A synthetic vision system might be able to incorporate and prominently display information from aircraft performance calculations and inertial sensors to understand deceleration trends and better inform pilots of which taxiway to take (or to avoid) during the landing rollout as well as help pilots understand if the current braking and deceleration are inadequate to successfully stop prior to the end of the runway. • Improved awareness • Can que pilot to adverse conditions or trends • Information of runaway boundaries (edges) could be provided to the pilots

Note. Landing Distance Available (LDA); Runway Overrun Awareness System (ROAAS)

When Experts were asked whether SVS would help in the event of an engine failure, 59 Experts responded with 32.2% (*n* = 19) indicating SVS would not be a benefit in this situation. Additionally, 67.8% (*n* = 40) respondents indicated they thought SVS may help during an Engine Failure situation, among those Experts, 52.5% (*n* = 31) indicated the benefit would be dependent on the display type with 77.4% (*n* = 24) of those who thought benefits are dependent on the type of display, indicated HUD would be the most beneficial display type (Table 43; Figure 13). Examples of expert comments included decreased pilot workload, support with finding a suitable forced landing area, clearance from terrain, and visualization of the flightpath (Table 47).

Figure 13

Do you see a Concept Where a Synthetic Vision System may Help Prevent an Engine Failure

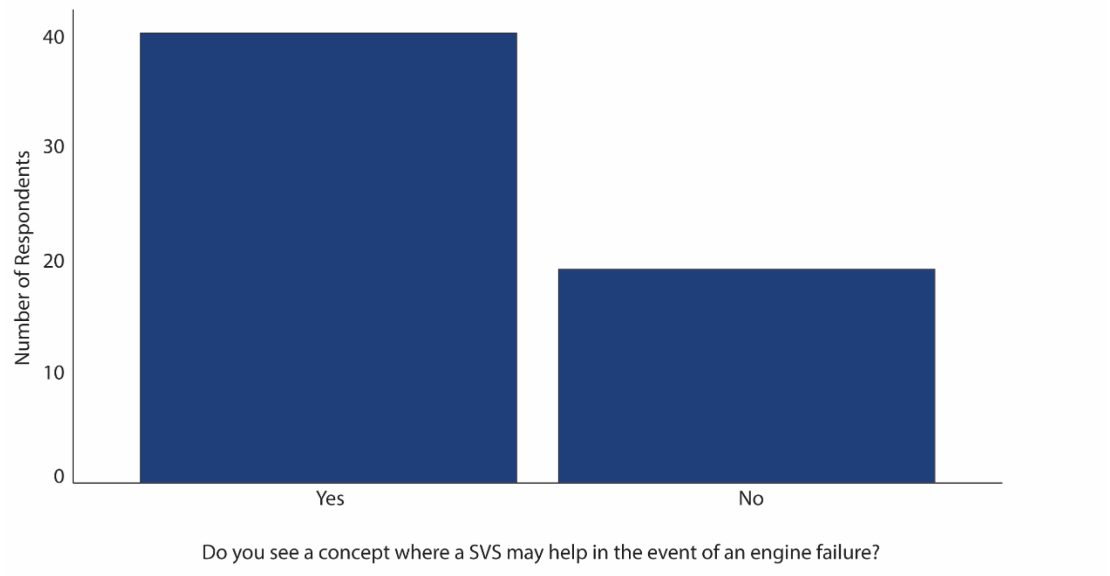


Table 47

Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision to Help in the Event of an Engine Failure

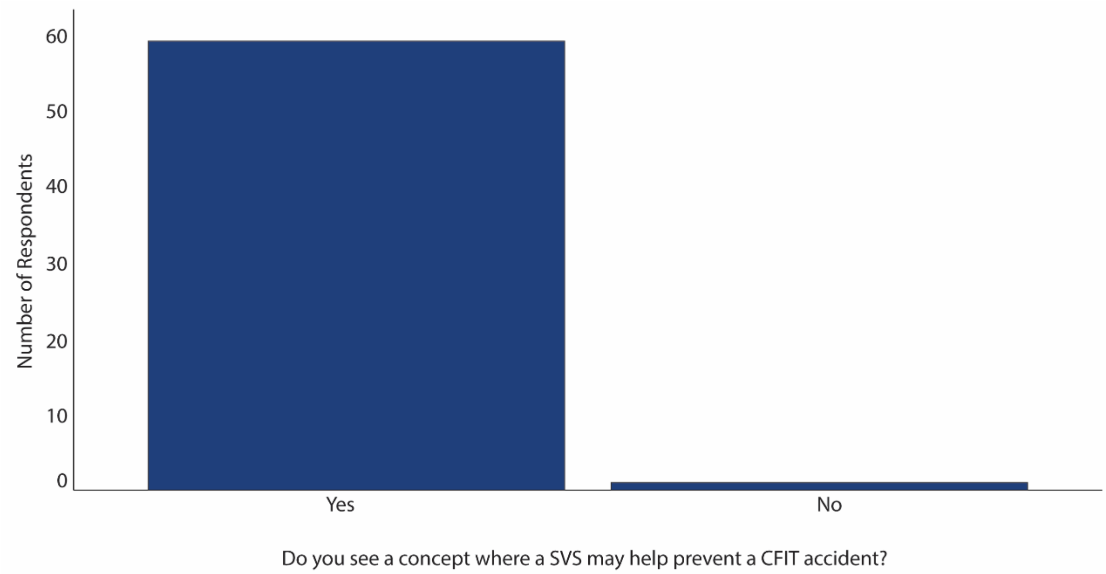
What are the benefits of synthetic vision to help in the event of an engine failure?
• With a high quality design, optical flow becomes important in order to appreciate the amount and rate of side slip (beta) created by the engine failure, which in turn could help in applying the proper amount of rudder deflection and aileron inputs to regain control of the aircraft • Visual awareness of energy state as well as directional divergence. • to keep the desired track and/or contingency OEI SID • There are engine out procedures on takeoff where a flight plan path changes from the normal departure. Visualization of the path on an SVS will help that understanding and reduce stress. • The SVS may help the flight crew maintain awareness of the flightpath during an engine failure. The flight crew may experience attentional tunneling while working through the engine failure checklist, causing them to lose awareness of the flightpath. The SVS imagery may make it easier for the flight crew to retain/regain SA in this scenario. • SVS would be no more help than a flight director with automatic engine out terrain guidance. • Still the same, get a better understanding of the surroundings to get quickly into a less critical situation • Situational and spatial awareness of airplane attitude relative to terrain and obstacles. • Shows runway surface and edges for an engine failure on take off up to V1 and after • Same as before - situational awreaness, especially on take-off. Extra symbology and runway length remaining. • Provide highway in the sky for optimal climbout or signal "abort" visually • Prevent CFIT or obstacle collision during partial thrust

What are the benefits of synthetic vision to help in the event of an engine failure?
• Particularly in single engine aircraft, high terrain, night, or even in urban areas to identify the least risky landing option. • OEI escape route may be a visual escape path that operators use in case of loss of one engine after T/O in peculiar conditions (high gradients req, trrain, noise abatment, NOTAMS, BIRDTAMS, etc.). Sometimes FMS provide the possibility to add these patterns as alternate/emergency escape routes on the navigation display (as a reminder), however the 3D visualization of such path is not provided on HUDs and PFD. SVS may help "seeing" obstacles and orography / terrain during such delicate manoeuvres flown follwoing one OEI condition. • Obstacle avoidance. • Most helpful in single engine aircraft - in which proper GLIDE SPEED/PATH can be shown. Pilots without glider experience tend to fly slower than optimal in an attempt to "stretch" the glide. A HWD/HUD can direct the pitch towards L/D Max primarily, then possibly laterally towards the nearest airport. • Maintaining clearance from terrain • Increased SA on terrain/obstacles • In low vis takeoff with engine failure you can easily monitor runway remaining when performance is limited. • In Falcon 8X using HUD my precision is better during engine failure on takeoff (V1 failure). • In a OEI scenario, the aircraft may not be able to maintain the desired altitude. Having better situational awareness regarding terrain/obstacles would be beneficial. • Improved SA. Reduce mental workload. • Improved awareness • If the scene was correct, and the pilot was having difficulty maintaining centerline, it would lead the pilot to centerline intuitively I think. • If it shows airports or safe off-airport landing sites. • If automatically integrated and turn on, the SVS could provide guidance in form of best glide and nearest airport/runway • ID safe LZ or runway, provide vector cues and direction to mnvr • Having a straight forward simbology, pathway like, that reduce cognitive processing and help pilot with flight path management to comply with performance requirements . • glide path, ratio, night, terrain locations, alternate landing sights, especially at night. • Flight guidance is actually more important than SV, but SV can assist in situational awareness. • Depending on the scenario / situation would provide more resources/info for the pilots • Decreased pilot workload in trying to assess aircraft state in a mentally tasking moment. • Better situational awareness can lead to a better outcome • Better opportunity to find a suitable forced landing area • Avoids the problem of symbology becoming HUD limited in a crosswind into the dead engine • As already discussed, energy awareness cueing while able to keep head outside the cockpit • Again, not binary answer. It might. Where in the EF sequence? At EF? Continued takeoff and climb? What type of aircraft, one with guaranteed OEI performance? What about rotorcraft CAT A balked T.O. or continue to land after engine fail?

Note. Bird Strike Risk or Warning NOTAM (BIRDTAM); Notice to Airmen (NOTAM)

When asked whether SVS may help prevent a CFIT situation, 60 Experts responded to the question. Of those Experts who responded, 98.3% (*n* = 59) indicated, yes, they see a concept where SVS may help prevent a CFIT accident (Figure 14). In addition, of those 60 respondents 63.3% (*n* = 38) of the Experts indicated the benefit from SVS during a CFIT situation is dependent on the display used, with 71.1% (*n* = 27) of those 38 indicating HUD or HWD display would be the most beneficial and 31.6% (*n* = 12) of Experts indicating HDD would be the most beneficial display to use (Table 43). Expert feedback focused mainly on the benefits of terrain and obstacle depictions (Table 48). One Expert respondent noted, "No more than EGPWS.[15] When actually flying in mountainous terrain with SVS, I consistently find the view out the window is much more compelling than the SVS generated terrain heads down. SVS heads up merely serves to distract and block natural vision. SVS heads up also will be slightly misaligned with actual terrain, particularly where distinct edges can be seen such as mountain ridges with a skyline background or island shores. This is very distracting, and my mind has difficulty focusing my eyes on either the natural vision or synthetic vision - I find it very problematic." Another Expert respondent noted that the benefit of SVS may depend on the depiction (i.e., logic and threat-color representation of the terrain).

Figure 14
Do you see a Concept Where a Synthetic Vision System may Help Prevent a Controlled Flight into Terrain Accident



[15] Enhanced Ground Proximity Warning System (EGPWS)

Table 48

Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision to Help Prevent a Controlled Flight into Terrain Accident

What are the benefits of synthetic vision to help prevent a controlled flight into terrain (CFIT) accident?
• Yes - the terrain overlay from SVS may significantly reduce the risk of CFIT compared to if the SVS was not present. This could particularly be the case in VFR nighttime flight where the flight crew is not using ILS or GPS guidance. • warn the flightcrew about obstacles • That's the whole point of synthetic vision, no? • Terrain situational awareness when terrain is not clearly visible due to low light or weather. • terrain awareness in low vis • Terrain awareness and cueing. With appropriate/accurate/reliable intertial reference, all options can be considered • Terrain and obstacle awareness • terrain ahead avoidance • Synthetic vision database has capability to graphically identify terrain and obstacles. • Synthetic vision can depict terrain and obstacles to help pilots understand their position in relation to those hazards and take action to avoid them. • Synthetic vision allows a pilot to see obstacles in lower-visibility situations. • SVS provides better situational awareness for terrain and obstacles. • SVS can present a picture of the terrain if not seen. • situational awareness, safety case • Situational awareness • situational awareness • situational awareness • Situational and spatial awareness of airplane relative to terrain and obstacles during low visibility and night flight operations. • Situation awareness • Seeing the terrain generally helps the pilot understand what to expect and question what is going on if they see themselves getting close to terrain when it is not expected. • Seeing said terrain synthetically • Greater Situational Awareness. Drastically improved terrain/obstacle awareness, particularly at night or extreme visual conditions in mountainous areas or cities • Prevent CFIT or obstacle collision during partial thrust • SA of terrain in a "out of window view" if this is presented on HMD/HUD • Maintaining clearance from terrain • On IMC it provides an outside view of surroundings terrain when not seem by real vision • No more than EGPWS. When actually flying in mountainous terrain with SVS, I consistently find the view out the window is much more compelling than the SVS generated terrain heads down. SVS heads up merely serves to distract and block natural vision. SVS heads up also will be slightly misaligned with actual terrain, particularly where distinct edges can be seen such as mountain ridges with a skyline background or island shores. This is very distracting and my

What are the benefits of synthetic vision to help prevent a controlled flight into terrain (CFIT) accident?
mind has difficulty focusing my eyes on either the natural vision or synthetic vision - I find it very problematic. • Night VFR, unfamiliar mountainous terrain • NASA had a SV project that focused specifically on CFIT and Runway Incursions. • It would potentially give you a display of terrain earlier or alert you to presence of terrain if spatially disoriented • It is the biggest benefit of SVS. IFR or night VFR only. • increases SA on terrain/obstalces • Increased awareness as a initial barrier to work together with TAWS • Improved awareness • If the scene was correct, it may help convey the gravity of the situation better than instruments. • Identify terrain and obstacle height and location. Provides warning of proximity warning and how to potentially avoid and navigate around. • Highway in the sky that was color coded, color coded terrain wireframes • Excellent for CFIT avoidance, especially at night and reduced visibility conditions • enhances the SA on environmental features, especially during descent into high terrain, valley • Enhanced situational awareness. • Enhanced situational awareness • Enhanced awareness of obstacles and aircraft energy state as well as TO/GA cueing • During IMC flight, the SVS provides great terrain SA based on database. • Depicts the terrain that you are about to impact • Compelling presentation of terrain • Clear description of obstacles • Awareness of terrain. • Awareness of descent creep, low visibility conditions. • avoid hazards, provide FPV cues to clear threat • Answered previously • Again, yes it might. There are variables and other factors. How is threat terrain depicted, for example one display manufacturer chose to depict threat terrain from aircraft altitude to 100' above aircraft as orange and greater than 100' red, what does that tell a pilot? Is a FPV required? What are the SVS cues relative to distance to terrain? Is a TAWS/HTAWS installed and functioning? • Ability to render terrain during contact approaches or inadvertent night weather entry • 3D view of terrain ahead during low vis conditions.

Note. Enhanced Ground Proximity Warning System (EGPWS)

Regarding the benefit of SVS in preventing or recovering from an aircraft upset (e.g., stall, spin), 59 Experts responded. Of those 59, 62.7% (n = 37) indicated they thought SVS would help during an aircraft upset situation (Figure 15). Moreover, of those 59 Expert respondents, 44.1% (n = 26) considered the benefit of SVS during an aircraft upset to be display dependent. Of those 26 Experts, 73.1% (n = 19) indicated the most beneficial display for an aircraft upset is HUD or HWD (Table 43). Expert comments were mixed. For example, comments mentioned specific symbology elements that could be beneficial, such as energy management symbology and a flight director (FD), and that SVS provides a general better understanding of the external world. (Table 49).

Figure 15

Do you see a Concept Where a Synthetic Vision System may Help a Pilot Prevent or Recover from an Aircraft Upset

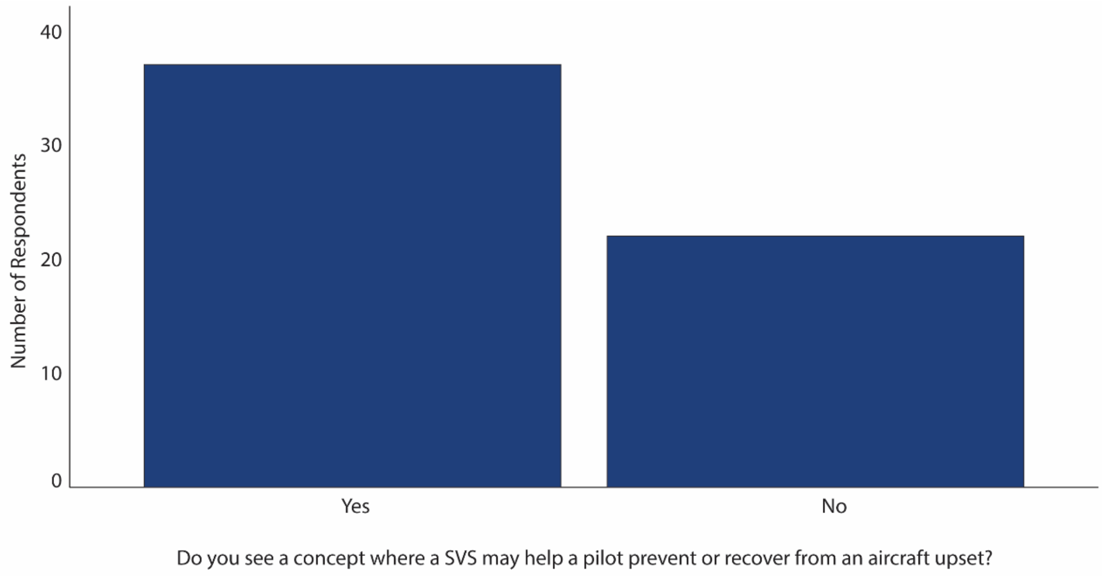


Table 49

Open-ended Text Responses When Asked, What are the Benefits of Synthetic Vision that may Help a Pilot Prevent or Recover from an Aircraft Upset (for Example, a Stall, Spin, or Unusual Attitude)

What are the benefits of synthetic vision that may help a pilot prevent or recover from an aircraft upset (for example, a stall, spin, or unusual attitude)?
• There may be some cases where SVS would improve upset recovery performance. It could be marginal. SVS imagery with color-coded blue-over-brown imagery would be needed for there to be a benefit of SVS. • The use o Pathway associated with energy management simbology intuitively saying to the pilot how to change attitude and apply/reduce thrust • see CAST ASA[16] JSIT/JSAT reports • situational awareness, safety case • Situational awareness, however there is specialized symbology assisting in unusual attitude recovery for all display types.

[16] Commercial Aviation Safety Team, (2014). Airplane State Awareness Joint Safety Analysis Team: Final Report Analysis and Results. https://www.cast-safety.org/pdf/JSAT-ASA_FinalReport_June2014.pdf

What are the benefits of synthetic vision that may help a pilot prevent or recover from an aircraft upset (for example, a stall, spin, or unusual attitude)?
• Situational and spatial awareness of airplane relative to terrain and obstacles during low visibility and night flight operations. • recover the control of the aircraft with more precision and avoiding exceeding the aircraft limitations, when possible. • quicker recognition of recovery path • Provide absolute orientation visually • pilot may have a better view of the outside world, even synthetic. • Only high quality designs improve the ability to recover from an upset. Designs meeting the ASA SVS FAA AC 20-185A would benefit the pilot during upset recovery • Maybe provide SA during IMC • It would help in the clouds • It depicts the ground while you may be IMC • In the light GA community there is sometime a confusion recognizing a spin versus a spiral dive. A flight director and/or G meter could assist in the correct recovery. Synthetic vision could be programmed to identify and announce a spin versus spiral dive (not a spin). • I can clearly envision it helping with unusual attitudes because it would make the horizon more readily available in the field of view • High field of regard HWD may offer highly intuitive horizon information. • helps to augment correct attitude and power setting • Help visualize distance to ground and a faster interpretation of how to recover the airplane. • Gives better cues for recovery • Fly the aircraft first and then figure out what obstacles have to be avoided. • Energy state awareness • Didn't [NAME] run a study on this? Not sure about spins. stall prevention would likely rely on other, non-SV cueing (AoA, FPV, airspeed awareness cues). UA's, yes. Didn't [NAME] run a study on this? • depict the flightcrew with the actual environment • Decluttering of data, immediate sources of upset recovery information • cues readily available and displayed clearly on HUD, HWD, pilots follow indications for quick and safe recovery, reduces disorientation • Compelling view of aircraft state. • Can cross cue FMS guidance with outside the cockpit cueing. • Better understanding of the external world to recover from a spatial possible confusion • Better pitch and roll reference with synthetic vision • Better awareness of sky/ground direction. • assist with disorientation during low vis • All needed flight info easily accessed by the pilot.

Note. Bracketed text represents redactions.

4.3.10 Combined Vision Systems

Focusing on CVS, which merges an SVS and an EVS image into one view, when asked if there were any safety and/or operational benefits of a CVS dependent on the display type, 58 Experts responded to the question. Of those 58, 91.4% (*n* = 53) of respondents indicated "Yes", the benefits are dependent on the display type used for CVS. Of the 53 who responded that benefits are display dependent, 88.6% (*n* = 47) noted HUD was the most beneficial display for CVS; 56.6% (*n* = 30) indicated HWD as most beneficial, and 30.2% (*n* = 16) reported HDD as being the most beneficial (Table 50). A common sentiment for open-text responses indicated the CVS benefits were related to redundant information presented from on-board sensors, not just from a database, making it easier to detect discrepancies (Table 51).

Table 50

Safety and/or Operational Benefits of a Combined Vision System: Most Beneficial Display Type

Display	Count (n)	Percentage (%)
Head-up Display (HUD)	47	88.7
Head-worn Display (HWD)	30	56.6
Head-down Display (HDD)	16	30.2

Note. *N* = 53. Respondents were asked to select all that apply.

Table 51

Open-ended Text Responses When Asked, What are Some Safety and/or Operational Benefits of a Combined Vision System? A Combined Vision System Merges an Enhanced Vision System and a Synthetic Vision System into a Single View

What are some safety and/or operational benefits of a combined vision system? A combined vision system merges an enhanced vision system and a synthetic vision system into a single view.
• tremendous benefit due to much soft transition from virtual images to real images during all ground and/or approach phases
• The same benefits of the SVS with assurance that the SVS is correct (by merging / overlaying imagery). The EVS provides real time information that SVS may not be able to provide depending on the design (e.g., other aircraft and surface vehicles).
• The key word here is continuity and consistence of information to the pilot. The less perceivable for the pilot is the transition from EVS to SVS system, the better.
• The ability to use real time sensor image to verify the aircraft position with features on the ground combined with the synthetic build out of additional features that are not visible with natural or enhanced vision.
• SV can be used for visual momentum, awareness of EV, possibly failure mitigations
• Smooth transition between low/no visibility conditions on approach into the landing environment/touchdown.
• Situational awareness, safety case improvement
• situational awareness, safer approaches, reduced pilot workload
• Situational awareness in extremely low vis conditions all the way down final.
• Situation awareness and reduced minima, while maintaining heads up.

What are some safety and/or operational benefits of a combined vision system? A combined vision system merges an enhanced vision system and a synthetic vision system into a single view.
• Situation awareness , crew awareness , operational minimus credits • Single point of information for the crew. • Same os synthetic vision • Same as before • Safety: gives complete picture of real time hazards as well as obstacles not viewable with FLIR sensors • safety and operational benefits of a combined vision system when made to meet regulation 91.176, operational benefit is operations down to touchdown. Being able to see real-time environment (vehicles/wildlife, objects), and penetrate weather (limited with IR based EVS during heavy fog and water particles, unencumbered with Millimeter wave radar) • Reduces crew workload. • Reduce minima by enhancing external references Better consistency checks Ease transition to enhanced visual and natural vision references • Real-time out the window imagery of terrain, obstacles, and runway environment in low visibility or night conditions. • Provides real time pictorial position information within the EV sensor FOV coupled with "clarity" of outside scene provided by the graphical depiction from SV to allow pilot better awareness of position in the z and y axes. • Provides multiple levels of information in one location. • Presents synthetic and real data into heads up display that also displays basic flight instrumentation. • On a well designed system, the SVS allows further reduction in minima (consistency check, proper crew alert in case of failures). • Obstacle avoidance, CFIT risk reduction. Enhanced aeronautical decision making. • More awareness and enhance safety. • Low visibility operations, both in air and on ground. • Its comforting to know the EVS and SVS agree on postion • It augments synthetic vision with active vision imagery which assists in detection of objects/terrain in real time. • Increased situational awareness • Increased SA • Improved safety margin for EFVS approaches. Better SA with EVS does not provide visual cues. • Improved SA. CFIT avoidance. Reduce runway incursions. • Improved flight crew awareness of terrain, geographical features, expected obstacles (e.g., wires), and unexpected obstacles that produce a heat signature (e.g., runway incursion) around the runway environment and along the flightpath. EVS portion of CVS could improve flight crew detection of runway visual information at/before the DA/DH. CVS may also improve the flight crew's ability to detect inaccuracies in the ILS or GPS-based flight guidance (e.g., localizer bend). CVS may also reduce crew workload during critical points of flight operations (e.g., at the DA/DH, or low-visibility taxiing). These could all result in operational benefits, such

What are some safety and/or operational benefits of a combined vision system? A combined vision system merges an enhanced vision system and a synthetic vision system into a single view.
as new low-visibility operational authorizations when CVS is in use. In turn, this would improve the operational tempo of the NAS and reduce the number of flight delays and cancellations. • Improved awareness and redundancy • Improve situational awareness. • I'm not sure what an enhanced vision system is,,,,and it hasn't been defined here yet. • I think a CVS would be beneficial for all phases of flight to include recognizing the runway environment sooner. • Having a CVS would immediately tie EFVS to SVS and differences would be readily apparent. • Greatly increased SA and reduces CFIT. Allows an aircraft to safely depart and land in reduces weather minima (up to nil visibility when well implemented) • Good for correlation of images. If they overlay well, then you have better confidence in the system. • EVS and SVS can validate each other. • Even better as you combine the appreciation of the surroundings with the realtime information enhanced by a EVS for instance • Enhancement of outside view • EFVS allows earlier detection of thermal (IR/NIR) images of ALS and runway lights. But also other a/c, close-by traffic is generally detectedand made visible thrugh HUD/HMD. The EFVS lights are usabel for taking the decision to land, while actual lights might not yet be visible due to fog/mist/heavy precipitations (more rarely if blocked by clouds). SVS provides situational awareness of the environment: runway location, orogroaphy and obstacles, in some implementations it can provide detaisl of the airport taxiways and runways (when not cut out to make place to EFVS imagery). Additionally, CVS (EFVS and SVS) provide more possibilities to detect inconsistent (failed/shifted, erroneous/misleading) information: the two independent source of images need to provide a sound fused unique image in front of the crew and, when some inconsistency is detected this should trigger the pilot decision to interrupt approach (i.e. not to rely too much on a biased / misaligned/frozen portion of image). • Eases the transition to visual landing from instruments. • CVS is the best of both worlds - real-time and additional information superimposed on display. SVS cannot be used for landing credit because it does not provide real-time information. Sensors provide real-time information but they do not provide the opportunity to display additional information to provide enhanced situational awareness. • Better picture of entire environment. • Better over all SA. SVS can add visual elements outside of the EVS operational range. • Better fidelity of data viewed • back up to human sight, if done right can add a layer of redundancy of system management • Again, improved ability to scene match and ensure cues are both. O firmed correct, and legally sufficient to proceed. • added situational awareness • A real time representation showing unknown obstructions or intrusion on a compelling and easily discernable digital representation of the environment.

Note. Approach Lighting System (ALS); Near-infrared (NIR)

4.3.11 Respondents Employed at an Aircraft Operator or Air Carrier

Nine (12.9%) Expert respondents who indicated they work for an Aircraft Operator or Air Carrier were asked an additional set of questions unique to their experience. The types of operations are shown in Table 52; the most-frequently cited operations with 55.6% of operators indicating they operate Part 121 (Domestic and Flag Air Carriers; *n* = 5) and 44.4% indicating Part 91 operations (General Aviation flight operating rules; *n* = 4). Note that more than one person at each aircraft operator or air carrier surveyed may have completed the questionnaire.

Table 52

Operations Currently Conducted with Aviation Vision System Technology

Operation	Definition	Count (n)	Percentage (%)
Part 91	General aviation with general flight operating rules	4	44.45
Part 121	Scheduled air carriers with domestic, flag, and supplemental operations, both regional airlines and major airlines	5	55.6
Part 135	Commuter and on demand operations, including corporate, government and helicopter operations	2	22.2
Part 141	Flight schools	1	1.1
Other	-	1	1.1

Note. *N* = 9. Respondents were asked to select all that apply.

Of the nine Experts who indicated they work for an Aircraft Operator or Air Carrier, 55.6% (*n* =5) indicated they currently use an aviation vision system. With the highest percentage of respondents at 60.0% (*n* = 3) indicating they use SV, followed by 40.0% (*n* = 2) of respondents who use enhanced vision and combined vision (*n* = 2; Table 53).

Table 53

Type of Aviation Vision Systems Currently in Use

Aviation Vision System	Count (n)	Percentage (%)
Synthetic Vision	3	60.0
Enhanced Vision	2	40.0
Combined Vision	2	40.0
Augmented Reality	1	20.0

Note. *N* = 5. Respondents were asked to select all that apply.

The nine operator or air carrier Experts were asked what types of aviation vision systems are the most appealing. The highest response was combined vision (88.9%, *n* = 8), followed by both enhanced vision and SV (66.7%; *n* = 6). Table 54 provides the number of respondents for each aviation vision system. Thirty-three percent (*n* = 3) of Experts indicated their Aircraft Operator or Air Carrier was considering the acquisition of an HWD system for use on an aircraft during flight within the next 10 years. Of those three respondents, 66.7% (n = 2) further indicated the HWD will be used for SV, 33.3% (n = 1) stated plans to use enhanced vision or combined vision (n = 1). An additional 33.3% (n = 1) indicated the technology will be used for augmented reality in a simulator environment (Table 55 to Table 57).

Table 54
Most Appealing Advance Vision Systems (if No System Currently In Use)

Aviation Vision System	Count (n)	Percentage (%)
Combined Vision	8	88.9
Enhanced Vision	6	66.7
Synthetic Vision	6	66.7
External Vision	5	55.6
Augmented Reality	5	55.6
Other	0	0

Note. N = 9. Respondents were asked to select all that apply.

Table 55
Open-ended Text Responses When Expert Respondents Employed at an Aircraft Operator or Air Carrier Were Asked, What Types of Operations Does Your Company Conduct, Please Specify 'Other' Response

What types of operations does your company conduct, please specify 'Other' Response.
• 91K

Table 56
Open-ended Text Responses When Expert Respondents Employed at an Aircraft Operator or Air Carrier Were Asked, What Aviation Vision System Technology Will the Head-worn Display be Used With, Please Specify 'Other' Response

What aviation vision technology will the head-worn display be used with, please specify 'Other' Response.
• Head worn augmented reality simulator

Table 57

Open-ended Text Responses When Expert Respondents Employed at an Aircraft Operator or Air Carrier Were Asked, Please Share any Additional Feedback on Topics Covered in This Section

Please share any additional feedback on topics covered in this section.
• Our carrier will likely not consider any device unless there is operational credit. • I used JHMCS in the military and it is very helpful. It is very SA (situational awareness) enhancing and can help to prevent accidents. They will help to reduce pilot workload when it comes to interpreting information on the panel. It delivers flight safety info directly to your eyes while your head is pointed in any direction. I highly recommend acquiring these types of systems sooner so that they will be made more affordable to the masses sooner. • Aviation organizations should consider and discuss how technology can enhance aviation operations, safety risk management and even single pilot operations. Having used different sensors (FLIR, NVG, HMD, DVE, etc) FAA and industry should continue to partner finding what works, solutions etc.

Note. Enhanced Proximity Warning System (EGPWS); Joint Helmet Mounted Cueing System (JHMCS)

4.3.12 Respondents Employed at an Avionics Original Equipment Manufacturer

Of the 18 Expert respondents who reported employment at an avionics OEM, 17 responded to the question asking whether their current employer offered an HWD for use in an aircraft during flight. Of those 17 Expert respondents, 64.7% (*n* = 11) indicated their company currently offers an HWD, and 35.3% (*n* = 6) reported their company does not currently offer an HWD device. Of the six Expert respondents who currently do not offer an HWD, 50.0% (*n* = 3) of those Experts indicated their OEM plans to offer an HWD system in the future (Table 61 through Table 74). Note that more than one person at each Avionics OEM surveyed may have completed the questionnaire.

All 11 Expert respondents at Avionics OEMs that currently offer an HWD also offer some form of aviation vision system displayed on their HWD systems. The most common type of advanced vision offered was enhanced vision (81.8%; *n* = 9), followed by SV (72.7%; *n* = 8, Table 58).

Table 58

Type of Aviation Vision Systems Currently Offered on a Head-worn Display

Aviation Vision System	Count (n)	Percentage (%)
Enhanced Vision	9	81.8
Synthetic Vision	8	72.7
Combined Vision	6	54.5

Aviation Vision System	Count (n)	Percentage (%)
Augmented Reality[17]	5	45.5
External Vision	2	18.2

Note. *N* = 11. Respondents were asked to select all that apply.

The 11 OEM Expert respondents whose company offers an HWD provided the type of airframe on which the systems are installed; 63.6% (*n* = 7) reported an Airplane (Table 59). When asked if the current SVS on an HWD system offers pathway guidance symbology, eight Experts responded; of those, 37.5% (*n* = 3) indicated pathway guidance is offered.

Table 59

Type of Aircraft Where a Head-worn Display With a Synthetic Vision System is Currently Installed

Aircraft	Count (n)	Percentage (%)
Airplane	7	63.6
Rotorcraft	3	27.3
Other	1	9.1
None of the Above	2	18.2

Note. *N* = 11. Respondents were asked to select all that apply.

Of the three OEM Experts who indicated plans to offer an HWD in the future, 66.7% (*n* = 2) indicated the plans included offering EVS, SVS, and CVS as an advanced vison displayed on an HWD. One of those Experts (*n* = 1) also indicated plans to implement an XVS. The Expert respondents indicated that the avionics OEMs plan to incorporate these systems into airplanes and rotorcraft for general aviation, as well as several other operations (Table 60). One Expert indicated they plan to implement this technology in power-lift and drones. Of the two OEM Experts, one (50%) indicated a 1-3-year plan for HWDs, and the other indicated a 4-6-year plan to offer HWDs. The Expert OEM respondents were asked to provide additional open-ended responses about the type of systems, how these systems will be implemented, and their design philosophy; responses to these questions are provided in Table 61 through Table 71.

Table 60

Type of Future Operations Where a Synthetic Vision System Will be Offered

Future Operation	General Description	Count (n)
Part 91	General aviation with general flight operating rules	2
Part 121	Scheduled air carriers with domestic, flag, and supplemental operations, both regional airlines and major airlines	2

[17] Augmented reality was included as an option based on respondent feedback that they preferred the term “augmented reality” for displays that are “see through”.

Future Operation	General Description	Count (n)
Part 125	Commercial flights by airplanes with the capacity of 20 or more seats and maximum payload capacity of 6,000 pounds or more	2
Part 129	Foreign air carriers and foreign operators of U.S. registered aircraft engaged in common carriage	2
Part 133	Rotorcraft external-load operations	1
Part 135	Commuter and on demand operations, including corporate, government and helicopter operations	2
Part 141	Flight schools	0
Part 142	Training centers	0
Other	-	0
None of the above	-	0

Note. Respondents were asked to select all that apply.

Table 61

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, do you Currently Offer an Aviation Head-worn Display for use in an Aircraft During Flight, Please Specify 'Yes' Response

Do you currently offer an aviation head-worn display for use in an aircraft during flight, please specify 'Yes' Response.
• We have a low TRL solution but have offered HWDs to various customers. • In development • HWD system under current development

Note. Technology Readiness Level (TRL)

Table 62

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, in the Future, do you Have Plans to Offer an Aviation Head-worn Display for use in an Aircraft During Flight, Please Specify Response

In the future, do you have plans to offer an aviation head-worn display for use in an aircraft during flight, please specify response.
• The availability of any device is going to depend on market acceptance. Unless there is compelling evidence that people will buy and use such a device, why would anyone invest the time to design, produce and market one?

Table 63
Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, What Aircraft is the Synthetic Vision System Head-worn Display Currently Installed on, Please Specify 'Other' Response

What aircraft is the synthetic vision system head-worn display currently installed on, please specify 'Other' Response.
• In development for civil acft/market

Table 64
Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, why are you Considering Enhanced Vision

Why are you considering enhanced vision?
• To take advantage of existing rule (91.176) to offer expanded approach capability
• Low-visibility operational enhancement (reduced minima, better situational awareness), better night situational awareness/reduced workload

Table 65
Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, why are you Considering Synthetic Vision

Why are you considering synthetic vision?
• Workload reduction/safety enhancement provided by presenting a human-friendly representation of the navigation solution. Improved all-weather situational awareness and reduced minima
• To add Pilot SA for features that EVS sensor is not able to capture

Table 66
Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, why are you Considering Combined Vision

Why are you considering combined vision?
• Single vision system providing the best of all vision systems
• If designed and implemented correctly, this is the best of both technologies for pilot use

Table 67

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, why are you Considering External Vision

Why are you considering external vision?
• Customers considering aircraft configurations with reduced forward visibility, better hazard detection, better situational awareness, safer and more autonomous ground operations

Table 68

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, What is Your Design Philosophy for Determining the Optimal Level of Realism of the Synthetic Vision System as Implemented on a Head-worn Display

What is your design philosophy for determining the optimal level of realism of the synthetic vision system as implemented on a head-worn display?
• The display is monochromatic, and we limit the level of realism to avoid interference with EVS imagery necessary for reduction in minimums.
• Sufficient realism for pilot identification and recognition of rendered features, while still supporting differentiation between synthetic vs real/enhanced imagery.
• Photo-realistic leaning. Versus wireframe. Clearly computer generated, but a continuous solution with pleasing blended features.
• Photo-realism in not required, but wireframe is not adequate.
• Objective is to provide a human-friendly (ease of interpretation, low workload) representation of the aircraft state and navigation solution. Realistic depiction of terrain proximity and height are critical, highly conformal presentation of runways, obstacles, other aircraft also critical to prevent confusion/disorientation.
• Broad base of user feedback on MMI and functions before final validation and release. Optimize visual database content and fidelity, suitable graphics processor speeds and design, design for serviceability and maintainability. Validate against ETSO and/or regulator guidance or mandates appropriate for the function(s)

Note. Man Machine Interface (MMI)

Table 69

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, What is Your Design Philosophy for Integrating Aircraft Alerts into a Synthetic Vision System as Implemented on a Head-worn Display

What is your design philosophy for integrating aircraft alerts into a synthetic vision system as implemented on a head-worn display?
• Synthetic information should be easily discernable from active sensor vision systems and validation of synthetic information by other means is important given the compelling nature of these displays. Design philosophy of existing FARs and ACs are still relevant - timely annunciation and removal of hazardously misleading information, etc.

What is your design philosophy for integrating aircraft alerts into a synthetic vision system as implemented on a head-worn display?
• It will completely depend on what the ability to discern, locate and read (if applicable) the other alerts in the cockpit is; are there voice alerts, aural alerts, or only visual alerts? • Broad base of user feedback on MMI and functions before final validation and release. Optimize visual database content and fidelity, suitable graphics processor speeds and design, design for serviceability and maintainability. Validate against ETSO and/or regulator guidance or mandates appropriate for the function(s) • Alerts MUST be consistent with the HUD symbiology. They are part of the HUD symbol set. This includes alerts related to SVS. • Aircraft alerting must mimic or indicate to crew that a warning/caution is active.

Note. Man Machine Interface (MMI)

Table 70

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, What is Your Design Philosophy for Determining the Optimal Color for Symbology for a Synthetic Vision System as Implemented on a Head-worn Display

What is your design philosophy for determining the optimal color for symbology for a synthetic vision system as implemented on a head-worn display?
• We performed a multi-year study into this for the USAF. We determined a maximum of 5 colors are discernable in high ambient environments. We also found that dark blue is a very bad color to use and that blue symbology should be more of a robin's egg blue we call blue'. • Today it is all monochrome green. Color on a transparent display if very challenging. Next generations solutions will have limited color with good color separation to ensure color discrimination and local area contrast enhancement. • The same philosophy as our HUD displays. • The colors must meet the overall cockpit color philosophy and also comply with the FAA's ever increasing reach ionto what colors may be used. • Currently monochromatic. • Broad base of user feedback on MMI and functions before final validation and release. Optimize visual database content and fidelity, suitable graphics processor speeds and design, design for serviceability and maintainability. Validate against ETSO and/or regulator guidance or mandates appropriate for the function(s)

Note. Man Machine Interface (MMI); United States Air Force

Table 71

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, for a Combined Vision System, What is Your Design Philosophy for Merging an Enhanced Vision Image and a Synthetic Vision Image into one View

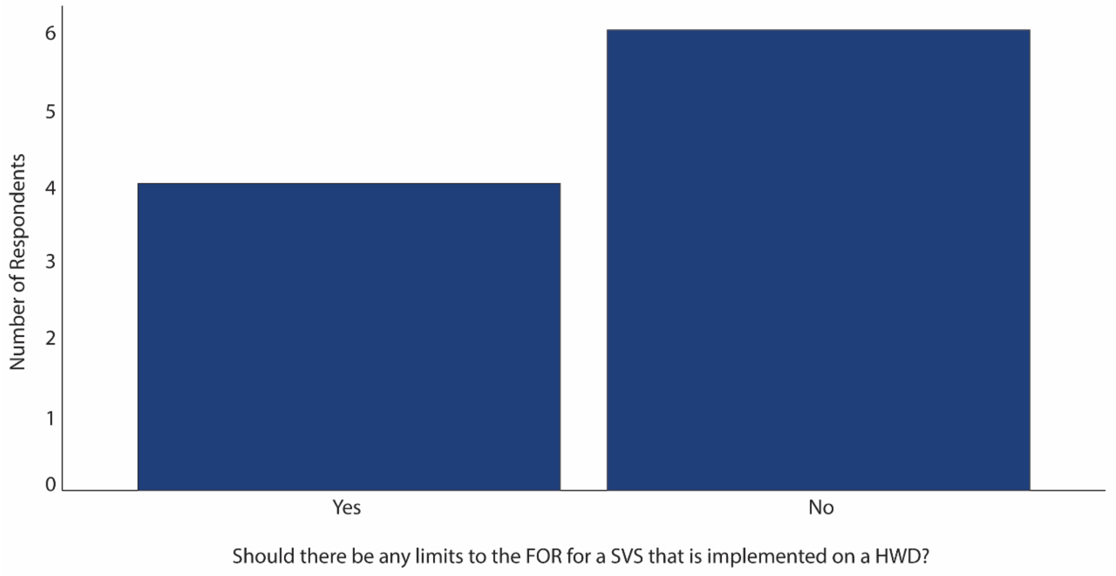
For a combined vision system, what is your design philosophy for merging an enhanced vision image and a synthetic vision image into one view?
• Too complicated for a short answer. • EV imagery has precedence and SV may be removed for approach. • Broad base of user feedback on MMI and functions before final validation and release. Optimize visual database content and fidelity, suitable graphics processor speeds and design, design for serviceability and maintainability. Validate against ETSO and/or regulator guidance or mandates appropriate for the function(s) • A seamless philosophy of our HUD displays. • A blended solution, not picture in picture.

Note. Man Machine Interface (MMI)

When asked whether the FOR should be limited for an SVS on an HWD, 10 respondents provided a response. Of those 10 Experts, 40.0% (n = 4) indicated the FOR should be limited for SVS implemented on HWD. Six (60.0%) of the avionics OEM Expert respondents felt that FOR should not be limited on SVS implemented on HWD (Figure 16).

Figure 16

Should There be a Limit to the Field of Regard for a Synthetic Vision System on a Head-worn Display



Moreover, 50.0% (n = 5) OEM Experts indicated that the FOR for an SVS on an HWD should vary for different aircraft (Figure 17). Open-ended responses for these questions were also collected; the responses are presented in Table 72 through Table 74.

Figure 17
Should the Field of Regard for a Synthetic Vision System on a Head-worn Display be Different for Different Types of Aircraft

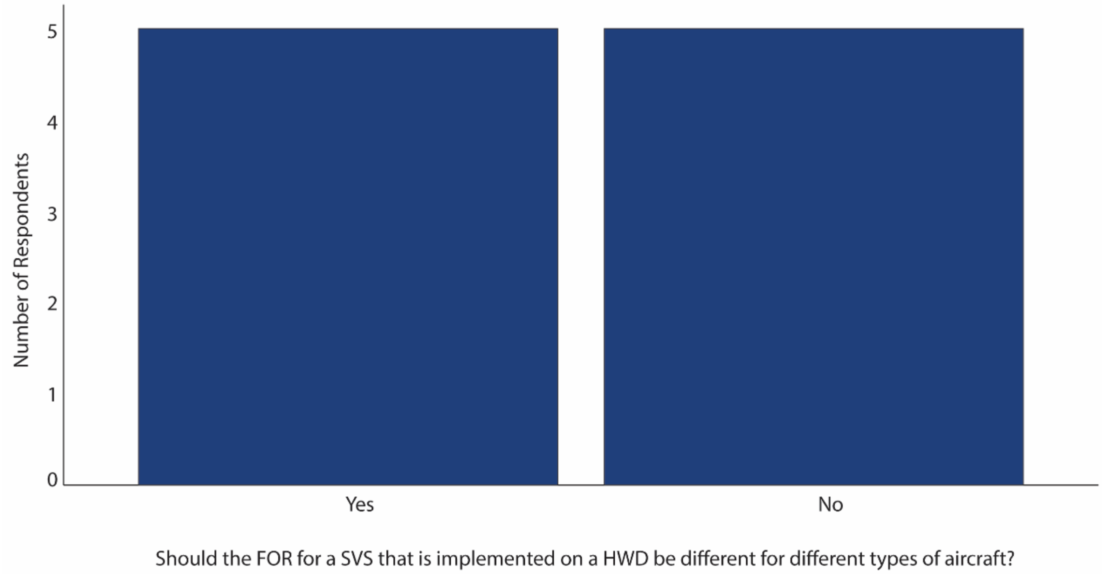


Table 72
Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, Should There be any Limits to the Field of Regard for a Synthetic Vision System That is Implemented on a Head-worn Display, Please Explain 'Yes' Responses

Should there be any limits to the field of regard for a synthetic vision system that is implemented on a head-worn display, please specify 'Yes' responses.
• While it will likely not be conformal, the FOV must be sufficient to allow pilots to locate threats. for example, it the HWD shows traffic in a certain location, but it isn't in that location, it will be confusing. So it may require conformal SVS, and how do you do that with a device that will change position as the pilot changes the head position? Not like a HUD in this regard. • There will be implementation specific differences to prevent obscuration of flight deck information and to ensure crew coordination is optimized. e.g.: full FOR may be operationally useful for ground operations, but not provide an operational enhancement in flight • MMI and user validation must be considered to optimize the support for the required critical functions and to manage the information displayed such as to avoid "saturating" or overwhelming the user, with safety of flight in mind

Note. Man Machine Interface (MMI)

Table 73

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, Should the Field of Regard for a Synthetic Vision System That is Implemented on a Head-worn Display be Different for Different Types of Aircraft, Please Specify 'Yes' Responses

Should the field of regard for a synthetic vision system that is implemented on a head-worn display be different for different types of aircraft, please specify 'Yes' responses.
• The field of regard can be affected by multiple airframe design issues, and tailoring the field of regard to the specific airframe makes sense in all installations. • Similar but appropriate for the HMD technology and use cases • Rotorcraft are a good example of an aircraft that will have significantly different operational requirements vs. fixed wing aircraft. • Not so much different aircraft, but rather different operations... low altitude flight demands more field of view than high altitude flight. Flying in degraded environments demands more field of view than when it is clear.

Table 74

Open-ended Text Responses When Expert Respondents Employed at an Avionics Original Equipment Manufacturer Were Asked, Please Share any Additional Feedback on Topics Covered in This Section

Please share any additional feedback on topics covered in this section.
• Please share these results with industry! • I would encourage you to study whether a pilot will wear a device like this. Cost is a big driver for GA pilots. Another is the amount of time a pilot is willing to wait for the HWD to initialize. • Happy to chat....[Email]

Note. Bracketed text represents redactions.

4.4 Conclusion

We have reported the results of a questionnaire that was administered to 70 individuals with self-reported moderate or greater familiarity with SVSs or HWDs. This survey of expert opinion aimed to gain insight from experienced users on the current state, future directions, and human factors or operational considerations of these technologies. Given the recent increased operational use of aviation vision systems and HWDs, there are now more individuals with direct hands-on experience with these technologies than in previous years. We aimed to survey civil aviation authority test and evaluation pilots; aircraft operator or air carrier pilots; simulator training center instructors; representatives from avionics and aircraft OEMs; human factors researchers; aviation vision system consultants; and others who may have experience using or evaluating these technologies.

Expert respondents identified safety benefits of SVSs, such as enhanced situation awareness for all phases of flight, especially during non-precision approaches, Category I and Category II approaches, landings and missed approaches, and nighttime operations. HUD was viewed as the most beneficial display type, followed by an HWD. Expert concerns with SVSs centered on the accuracy of terrain and obstacle database information, susceptibility to GPS spoofing or jamming, and display clutter or colorization. For concerns related to display compellingness, recommended countermeasures included simulator training with an experienced instructor who provides constructive feedback, and training focused on scenarios that invoke cognitive tunneling when transitioning from the visual to instrument segment to promote targeted learning, turning off changing or flashing symbology (which are likely to draw attention), prohibiting photorealistic terrain depictions, and other design features such as automatic and graceful decluttering especially at the decision altitude (DA)/DH of an approach. Regardless, there was skepticism that training alone would be sufficient as a countermeasure.

Specific to SVS on an HWD, concerns were related to HWD fitment, HWD shifting over time, and pilot comfort; effects of monocular and binocular optics; potential for increased risk-taking behavior; view conformation; potential for visual distraction and confusion (e.g., SVS depiction and potential distorted view of the external visual scene, especially when surrounded by bright lights or a "sea of lights" in a metropolitan area); blocking or obscuring the real-world scene; and other operational concerns such as donning an O_2 mask and the practicalities of routine maintenance. As an example, there were concerns about an HWD shifting during hard or balked landings. Training recommendations centered on emphasizing system limitations, simulator training for engine failures at different reference speeds, crew coordination, the importance of maintaining a normal visual scan, symbology and runway markings, display controls and adjustments, traffic and obstacle identification, and the effect of the field of regard for different phases of flight.

Expert respondents employed by an aircraft operator or air carrier reported that SVS, EVS, and CVS were already in use by their employer. For those not currently using aviation vision system, CVS was the most appealing option. Several Experts indicated their employers were considering acquiring HWDs within the next 10 years. However, one Expert noted that their carrier will likely not consider any device unless there is operational credit. Another Expert noted the need for continued aviation organization partnership to discuss how technology can enhance aviation operations, safety risk management, or even single-pilot operations.

Expert respondents employed by an avionics OEM reported that they have offered HWDs to various customers, that they currently offer an SVS on an HWD for airplanes and rotorcraft, or that they currently have HWDs in development. For Experts who are considering an EVS, their motivation centered on taking advantage of existing FAA regulations for expanded approach capability. For Experts considering SVSs, their motivation was related to reduced pilot workload and increased situation awareness provided by SVS features that EVS sensors cannot capture. For Experts considering CVS, responses indicated a belief that CVS provides the best of all aviation vision system technologies. When discussing the optimal level of realism for SVS imagery, responses for CVS HWDs noted the use of monochromatic displays, limiting realism to avoid SVS interference with EVS imagery, and allowing for differentiation between EVS and SVS imagery while still allowing for pilot identification and recognition of features. Other respondents discussed the balance between photorealistic and wireframe SVS imagery, with comments that their SVS image was "photorealistic-leaning"; another noted that photorealistic was not required, but wireframe was not adequate. In general, conformality with the external scene was emphasized, along with a realistic depiction of terrain proximity and height. For determining the color of SVS on HWDs, most Experts reported monochromatic colorization. For Experts who mentioned color, recommendations included limiting the color set to five and avoiding certain colors, such as dark blue; challenges with implementing color on a transparent display; and the importance of color separation to ensure color discrimination. When asked about design philosophy for CVSs, one Expert reported that EVS imagery takes precedence over SVS imagery, and that SVS imagery may be removed for approach. Focusing on Expert responses on field of regard, responses suggested a need to vary field of regard for different aircraft and airframes, as well as for different operations (e.g., “low altitude flight demands more field of view than high altitude flight. Flying in degraded environments demands more field of view than when it is clear” and may necessitate different field of regard.)

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6.0 Appendix

6.1 Example Pilot Training Topics for Synthetic Vision Systems Implemented on Head-worn Displays

A major challenge in integrating new flight deck technology into aircraft is training pilots to leverage enhanced safety features while managing potential risks associated with new or altered processes and procedures. In the case of an SVS implemented on an HWD, there are two types of technology that require consideration: the display type and the display image. Unlike a HUD, which is mounted in a fixed position and located directly between the pilot and the windscreen, an HWD moves with the pilot's head and maintains the display alignment with the pilot's head and eyes. Also, unlike a HUD or HDD, the HWD is always in the pilot's FOV, unless it is turned off, removed, or SVS (or other imagery) information is deselected. The aircraft flight information, symbology, and synthetic imagery displayed on the HWD must account for variations in the pilot's head position, orientation, line of sight, and dynamic changes to the aircraft's position. The HWD may slip or move on the pilot's head, or the headtracking system and coordinate reference frame of the symbology may also shift and present erroneous information (SAE ARP6377, 2023). Pilots should be trained on procedures to minimize the occurrence of these events and to quickly recognize and respond to erroneous information. Here, we provide example pilot training topics derived from interviews with subject matter experts; a review of relevant industry standards documents (RTCA, 2011; SAE ARP6377, 2023); and key themes identified in the literature review and survey study reported in this paper. The examples are categorized within the following areas: hardware and software; ergonomics; aircraft flight information, symbology, and imagery; abnormal, non-normal, and emergencies; associated systems and components; crew coordination procedures; ground training; preflight; taxi; takeoff; climb; cruise; descent; approach; landing; rollout; missed approach; balked landing; and post-flight. These examples do not constitute an exhaustive list and are not FAA required training. Finally, additional training should be considered for other types of implementations, such as unique SVS, HWD, and aircraft characteristics, for dual HWDs (one for each pilot), or for mixed display configurations, such as those incorporating an HWD with an HUD or an HDD.

6.1.1 Hardware and Software

- An overview of hardware and software, including databases, computer, display generation, wires/cables, sensors, and the HWD.
- Failure modes.
- The relationship between the glareshield-mounted optical tracker and the headtracking sensors in the HWD, and their effect on the scene depicted on the HWD.
- Limitations on the use of sunglasses, such as if sunglasses degrade the contrast between aircraft flight information, symbology, synthetic imagery, and the external visual scene. Training should include alternatives to sunglasses for flight operations in direct sunlight or high-brightness conditions, such as the use of any provided sun visors.
- Source of synthetic display imagery, such as an obstacle database and a terrain database.
- Process to update software or database information.
- Setup requirements using the Flight Management System (FMS).

- Connecting the HWD to the aircraft.
- Cleaning, transporting, storing, and maintaining the HWD.

6.1.2 Ergonomics

- Specific adjustment methods of the HWD so that each operator obtains the best fit and function for optimal viewing of displayed aircraft flight information, symbology, and synthetic imagery. This may include additional considerations to support the use of prescription eyeglasses, sunglasses, or emergency equipment such as oxygen or smoke masks.
- Adjusting padding and maintaining the optimal posture to ensure the best fit, and to avoid hot spots and HWD slipping.
- Techniques to readjust the HWD, as needed, following severe turbulence, sudden head movements, or other reasons that may cause the HWD to shift.
- Wearable time limitations to minimize the risk of headache, neck pain, or muscular stress due to the weight or balance of the HWD. Training should include indicators to recognize the onset of these discomforts.
- HWDs can be designed to display information to one or to both of the pilot's eyes. Training should include the effects of ocular presentation on the viewing of aircraft flight information, symbology, and synthetic imagery. In the case of a user-selectable monocular HWD, training should include the identification of the operator's dominant eye to use for display presentation.
- Adjusting the display position so that the operator's entrance pupil is within the dimensions of the HWD's exit pupil in order to ensure proper viewing of aircraft flight information, symbology, and synthetic imagery within the display FOV. The proper adjustment is based on the operator's interpupillary distance. Training should also include techniques for readjustment after severe turbulence, as needed.
- Structures and other obstacles within the flight deck that may limit outside viewability or that may hinder the operator from conducting an adequate HWD scan.
- Monochromatic adaptation.
- Dark adaptation time after doffing the HWD.

6.1.3 Aircraft Flight Information, Symbology, and Imagery

- Characteristics of the elements used to portray terrain, water, obstacles, airports, runways, lighting infrastructure, and signage in the SVS image. This should include symbology, color (i.e., for colorized displays), and presentation logic (e.g., differences in appearance during day vs. night; presentation when certain criteria have been met, such as distance or altitude thresholds).
- Characteristics of symbology elements, such as pitch, flight path vector (FPV), flare prompt, pathway guidance, or other symbology elements, to include color (i.e., for colorized displays), location, and presentation logic.
- Characteristics of all warning and failure flags or alerts, including color (for colorized displays), presence of attention-getting cues (e.g., pulsing, flashing, concurrent presentation of an auditory signal), location, and presentation logic.

- Characteristics of HWD symbology, such as an eye reference point symbol used to verify that the HWD is donned properly and that the full display area is available to the operator.
- Characteristics of aircraft flight information, such as airspeed, barometric altitude, attitude, turn and bank, rate of climb, and direction, including color (i.e., for colorized displays), location, and display logic.
- The effect of dynamic motion on the presentation of conformal and non-conformal flight information, such as events that may cause elements to visually interact (e.g., mixing/mingling, and masking) in a way that makes it difficult to view and use key parameters. Training should include the prioritization scheme for presentation of primary flight information (PFI).
- The use of controls to adjust brightness levels automatically or manually, contrast levels, enable non-uniform calibration, set range, select declutter, set the Flight Path Angle Reference Cue (FPARC), enable eye reference point symbol, display system information page, change or select HWD modes, or turn on/off.
- Display logic for how the HWD declutters when viewing HDD instruments, the overhead panel, or when the operator is not looking out the windshield. Decluttering or masking is to ensure an unobscured view when performing head-down tasks such as reading checklists or actuating switches or controls. When the HWD implements a masking feature that automatically removes flight information, symbology, or synthetic imagery from a predefined area, training should include the boundaries and logic of the masking on the display FOV.
- Effect of monochrome green color or colorization on the operator’s interpretation of critical elements in the external scene, such as airfield lighting infrastructure, traffic, airport signage, Visual Approach Slope Indicator (VASI), or Precision Approach Path Indicators (PAPIs).
- Relationship between display colors used for aircraft flight information, symbology, and synthetic imagery. Emphasis should be placed on discriminating each element and maintaining each element’s visibility when slewing results in overlays of similar colors (e.g., green symbology on green terrain).
- Visual illusions, such as disparity between SVS presentation and aerial perspective (i.e., distance based on the clarity of an object); false horizontal cues; structural illusion caused by aircraft abnormalities (e.g., glass, rain, snow).
- Differences between aircraft flight information or symbology presented on the HWD and the PFD HDD.
- Manufacturer-specific obstacle presentation techniques, such as windmills that look like rectangles, navigational fixes that have “flags”, densely populated areas of building that are shown only with a few building symbols.
- FOR.
- FOV.
- Display minification.
- Stall presentation, such as whether the SVS image is removed, or if it stays.
- Upset recovery presentation, such as whether the SVS image is removed, or if it stays.
- Image defects (possibly shading, edge glow, bright spots, distortion, veiling glare, image disparity in binocular systems.
- For CVSs, control functions to independently turn on and off SVS, EVS, or CVS data.

- For CVSs, SVS “cutout” areas for presentation of EFVS.
- For CVSs, differentiating between the sensor-based elements and the computer-generated elements.

6.1.4 Abnormal, Non-normal, or Emergencies

- The location, color (i.e., for colorized displays), meaning, and display logic for alerts, indicators, flags, annunciations, messages, or display features. Training should also include the appropriate operator response for each alert, indicator, annunciation, message, or display feature. As one example, the loss of aircraft flight information, symbology, or synthetic imagery may indicate misleading information or a loss of connection between the glareshield-mounted optical tracker and the HWD. The operator corrective action to reestablish a connection between the glareshield-mounted optical tracker and the HWD may include the operator repositioning their head to a forward orientation toward the optical tracker to try to reestablish a connection between sensors in the HWD and the optical tracker, waiting a specified amount of time, and then reverting to HDDs for controlling the aircraft if a connection is not made.
- Cues to instantly recognize unusual attitudes. If provided, training should cover any guidance information (e.g., recovery steering guidance commands) to recover from upsets or unusual attitudes. Training should include all foreseeable modes of upset, including crew mishandling, autopilot failure (including “slowovers”), and turbulence or gust encounters.
- Any limitations in HWD functionality or readability due to severe turbulence where there may be occlusion between aircraft flight information or symbology elements.
- Training should include events (e.g., system failures, unusual attitudes) where the operator should transition from the HWD to the HDD for controlling the aircraft.
- Loss of aircraft flight information, symbology, or synthetic imagery during all phases of flight.
- Cross-check techniques to recognize the improper presentation of SV elements with the external visual scene.
- For CVSs, cross-check techniques to identify misalignment of the EFVS sensor image and SVS image with the external visual scene.
- Procedures to follow if the SVS display appears to be misaligned with the external visual scene. For example, on an approach, the pilot may elect to continue the approach and landing if the required visual references have been acquired using natural vision. Alternatively, the operator may elect to go-around if the required visual references have not been acquired using natural vision. In other phases of flight, the operator should cease use of the HWD.
- Detecting runway incursions.
- Emergency procedures for an HWD failure for the PF and the PM.
- Emergency procedures for an SVS failure for the PF and the PM.
- Process to doff the HWD in emergencies.
- Emergency procedures, both with and without a PM display (if applicable).

6.1.5 Associated Systems and Components

- Characteristics of elements associated with systems and components, such as TCAS, TAWS, Helicopter Terrain Avoidance and Warning System (HTAWS), autopilot, or EVS. Elements may include color, location, and logic of any system flags, symbols, messages, alerts, or indicators.

6.1.6 Crew Coordination Procedures

- Crew procedures for using the PM display (if applicable).
- PF and PM communications, to include callouts to indicate transfer of aircraft control (e.g., such as when the PF dons or doffs the HWD), continue descent below the DA/DH or Minimum Descent Altitude (MDA), clearly communicate the decision to land or go around, and for abnormal, non-normal, and emergency operations.
- Duties of the PF and PM, crew briefings, procedures, and coordination items for SVS normal, abnormal, and emergency operations, including annunciation of published minimums and operation below the DA/DH or MDA. Emergency procedures, both with and without a PM display.
- Crew procedures if the PF loses HWD-based visual information, or SVS aircraft flight information, symbology, or imagery is erroneous or misleading, particularly during final approach. Consideration should be given to scenarios when the PF is wearing an HWD and the PM is not. This makes it more difficult to verify erroneous information and to develop and maintain a shared mental model.
- Coordination on heads-up scanning and heads-down scanning between the PF and PM for each phase of flight. The scanning position may depend on whether the aircraft has a dual-HWD installation, compared to a single-HWD installation, where the PM is more likely to remain in a heads-down scanning position to look at instruments and monitor the alerting systems for failures of systems, modes, and functions that are not displayed on the PFD or HWD.
- Use of the PM display (if present) to monitor the visual segment of the approach to verify the correct airplane approach trajectory.

6.1.7 Ground Training

- Required equipment for the flight operation.
- Understanding of the optimal SVS and HWD settings for different phases of flight and meteorological conditions.
- Activation of eye reference point symbology to assist with fitting the HWD so that the displayed symbology falls within the display FOV.
- How and where to read control labels, and any challenges while flying during the day or at night.
- The effect that a realistic, compelling display may have on attention, and techniques to avoid being drawn into the display as a complete picture.
- Not to rely on just SVS, and to use other sources of information, including what to use as the primary source of information for navigation and decision-making.
- An appreciation of distances in the synthetic world, and the use of any provided SV distance cues.

- Transitioning from SVS imagery to real-world natural vision for both the PF and PM.
- Understanding the operational concepts and the procedures under 14 C.F.R. § 91.175.
- SA CAT I concept and equipment requirements (FAA AC 120-118, 2018).
- Obstacle and terrain clearance awareness during day versus night.
- Maximum crosswind component.
- Steep approach limitations.
- Use of SVS for precision, non-precision, offset, steep, and special approaches.
- Importance of considering airfield lighting intensity.
- Limitations on the use of the PM display (if applicable).
- HWD operational characteristics, capabilities, and limitations of the ground facilities (Surface Movement Guidance and Control System [SMGCS]).
- Monochromatic terrain presentation (e.g., water, mountain ridges, topography, cultural areas, buildings).
- For rotorcraft, procedures for flat-light, whiteout, and brownout conditions.
- Proper HWD visual scanning techniques to mitigate the tendency for the displayed information to become an attention trap, and to support the acquisition and maintenance of situation awareness.
- For monocular HWDs, the use of monocular cues to support depth perception. This includes relative size (i.e., distant objects subtend smaller visual angles than near objects), texture gradient, occlusion, linear perspective, contrast/saturation differences, and motion parallax.
- FOV and FOR capabilities and limitations of the headset.
- A focus on pathway guidance (if applicable) and possibly the flight vector meaning.
- Realization that the presentation is conformal and may require different head movement as compared to HDD.

6.1.8 Preflight

- Preflight of aircraft modifications for HWD (e.g., power source, dataport cord connection, head tracking devices).
- Check for visual defects (e.g., possibly shading, edge glow, bright spots, distortion, veiling glare, image disparity in binocular systems).
- Verify obstacle and terrain database currency.

6.1.9 Taxi

- Depiction of expected visual references, such as taxiway edge lights, taxiway centerline lights, runway guard lights, signs, and markings. Differences in depiction at lower visibilities and with a monochromatic display.
- Verifying the SVS on an HWD depiction aligns with outside references (e.g., ensuring taximarkers in the natural vision match the SV).
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.

6.1.10 Takeoff

- Verifying the SVS on an HWD depiction aligns with outside references (e.g., ensuring runway markings in the natural vision match the SV).
- Confirm position on the correct runway for takeoff.
- Procedure to follow in case of an SVS on an HWD failure.
- Procedure to follow in case of an engine failure.
- Techniques to minimize glare and glow.
- How to distinguish between the SVS image and natural vision during takeoff.
- Representation of obstacles and terrain.
- Looking through the SVS image to see the external environment with natural vision.
- Detecting air traffic using natural vision while using an HWD with SVS.

6.1.11 Climb

- HWD depiction of conformal pitch axis in both caged and uncaged modes (high climb out angles).
- Representation of obstacles and terrain.
- Procedure to follow in case of an engine failure, including one engine inoperative (OEI) procedures.
- Looking through the SVS image to see the external environment with natural vision.
- How to divide attention between natural vision and SV.
- Detecting air traffic using natural vision while using an HWD with SVS.

6.1.12 Cruise

- Straight and level flight, accelerations, and decelerations.
- Normal and steep turns, climbs, and descents.
- Stall prevention and recovery, and unusual attitudes.
- Representation of obstacles and terrain.
- Possible wear time limitations, fatigue.
- Looking through the SVS image to see the external environment with natural vision.
- Divert airfield identification.
- Procedure to follow in case of an engine failure.
- How to divide attention between natural vision and SV.
- Detecting air traffic using natural vision while using an HWD with SVS.

6.1.13 Descent

- Depiction of visual references: airfield dome, runway centerline, fixes, and constraints.
- Expected sequence of visual cues during an approach in which visibility is at or above landing minima.
- Approach showing deviations above and below the descent profile for symbology/runway relationship.
- Representation of obstacles and terrain.
- Looking through the SVS image to see the external environment with natural vision.

- Divert airfield identification.
- Procedure to follow in case of an engine failure.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.
- A focus on speed and energy management while using the SVGS.

6.1.14 Approach

- Depiction of expected visual references with weather at minimum conditions.
- Expected sequence of visual cues during an approach in which visibility is at or above landing minima.
- approach showing deviations above and below glideslope (GS)/vertical path for symbology/runway relationship.
- Representation of obstacles and terrain.
- Use of FPARC.
- For operators wishing credit for low visibility operations (LVOs) predicated on use of the HWD/SVS:
    - Perform a SA CAT I approach to authorized minimums with calm winds.
    - Perform a SA CAT I approach to authorized minimums with 5 to 10 knots crosswind.
- Looking through the SVS image to see the external environment with natural vision.
- Divert airfield identification.
- Procedure to follow in case of an engine failure.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using an HWD with SVS.
- A focus on speed and energy management while using the SVGS.

6.1.15 Landing

- Crew coordination for PF transitioning to natural vision.
- Understand the compelling nature of the SVS and ensure natural vision is used at the applicable point.
- Representation of obstacles and terrain.
- Circling approaches and landing with AFM maximum crosswind.
- Transition from HWD to natural vision.
- Looking through the SVS image to see the external environment with natural vision.
- Divert airfield identification.
- Procedure to follow in case of an engine failure.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.
- A focus on speed and energy management while using the SVGS.

6.1.16 Rollout

- Depiction of expected visual references: airfield dome, runway centerline, runway remaining markers, overrun marking.

- Expected sequence of visual cues during a rollout in which visibility is at or above landing minima.
- Approach showing deviations right and left of the centerline for symbology/runway relationship.
- Looking through the SVS image to see the external environment with natural vision.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.
- Runway centerline deviation and overrun monitoring.

6.1.17 Missed Approach

- Depiction of expected visual references: airfield dome, runway centerline, fixes, and constraints.
- Expected sequence of visual cues during an approach in which visibility is at or above landing minima.
- Approach showing deviations above and below GS for symbology/runway relationship.
- HWD depiction of conformal pitch axis in both caged and uncaged modes (high climb out angles).
- Changes to the SVS display mode that occur during the missed approach procedure.
- Looking through the SVS image to see the external environment with natural vision.
- Divert airfield identification.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.

6.1.18 Balked Landing

- Depiction of expected visual references: airfield dome, runway centerline, runway edge lighting, fixes, and constraints.
- Expected sequence of visual cues during a balked landing in which visibility is at or above landing minima.
- approach showing deviations right and left of the centerline for symbology/runway relationship.
- Looking through the SVS image to see the external environment with natural vision.
- Divert airfield identification.
- How to divide attention between natural vision and SV.
- Detecting other air traffic using natural vision while using HWD with SVS.

6.1.19 Post-Flight

- Post-flight training items should be considered in accordance with the SVS on an HWD OEM recommendations. Items may include doffing the HWD, disconnecting the HWD from the aircraft, inspecting the HWD, and storing the HWD in accordance with OEM recommendations. There may be special consideration for long-term storage procedures.