

Augmentation of Cognition and Perception Through Advanced Synthetic Vision Technology

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Abstract

Synthetic Vision System technology augments reality and creates a virtual visual meteorological condition that extends a pilot's cognitive and perceptual capabilities during flight operations when outside visibility is restricted. The paper describes the NASA Synthetic Vision System for commercial aviation with an emphasis on how the technology achieves Augmented Cognition objectives.

1. Introduction

Augmented Cognition (AugCog) seeks to extend an operator's abilities via computational technologies that are explicitly designed to address information processing bottlenecks, limitations, and biases. Synthetic vision can be described as an emerging AugCog technology that increases a pilot's perceptual and cognitive capabilities, resulting in enhanced situation awareness, visualization capabilities, and attention to help meet national aviation goals of reducing the fatal accident rate and improving National Airspace System efficiency and throughput.

Synthetic vision serves to augment reality through creation of a "virtual visual meteorological condition" that emulates a visual flight rules environment regardless of actual weather or visibility conditions. Synthetic vision is not merely an ersatz for visual perception but instead, represents a suite of technologies that together meet, or extend, a pilot's natural capabilities in visual flight rules operations.

There are many conceptualizations of synthetic vision that range from relatively rudimentary 3-D displays of terrain information to more sophisticated, integrated synthetic vision systems. The NASA Synthetic Vision System (SVS) concept extends the basic concept beyond a depiction of how the outside world would look to the pilot if he or she could see outside the cockpit window, but additionally incorporates other innovative safety and situation awareness features that together significantly increase aviation safety and pilot efficiency.

The purpose of the paper is to discuss the effects of synthetic vision as a modulator of human information processing in realistic environments. First, synthetic vision is defined and the need of synthetic vision technology is explored. Next, the NASA Synthetic Vision System is described, followed by discussion of how the system supports pilot augmented cognition and perception. Finally, a summary of flight test research and future directions is provided that demonstrates the potential of Synthetic Vision Systems to substantially augment human information cognition and processing when applied to commercial aviation operations.

1.1. Synthetic Vision

A "synthetic vision system" is an electronic means of displaying the pertinent and critical features of the environment external to the aircraft through a computer-generated image of the external scene topography using on-board databases (e.g., terrain, obstacles, cultural features), precise positioning information, and flight display symbologies that may be combined with information derived from a weather-penetrating sensor (e.g., runway edge detection, object detection algorithms) or with actual imagery from enhanced vision sensors (EVS). What characterizes the Synthetic Vision Systems technology is the intuitive representation of visual information and cues in a manner analogous to what the pilot or flight crews would normally have in day, visual meteorological conditions.

1.2. The Need for Synthetic Vision

Humans have always had an enduring fascination with the miracle of flight. From the Greek mythological story of Icarus and Daedalus to the enthusiastic 100-year celebration of the Wright Brothers inaugural flight, our dream of

flying up high like a bird inspires the young and old alike. Rapid advancement in technology has compensated for our avian inadequacies. In the relatively short span of 100 years, we have progressed from flights of a few hundred feet to routine trips over oceans to distant parts of the world. Speed, altitude, and range all have increased a thousand-fold.

Aviation has also been witnessed the introduction of technologies to improve aviation safety as our thirst for efficiency and convenience have increased. The development of attitude indicators, flight management systems, instrument landings systems, and radio navigation aids have all extended aircraft operations into weather conditions in which forward visibility is restricted. Before these technologies were introduced, pilots often avoided flying in bad weather or did so at great personal risk. Today, commercial aviation is among the safest modes of transportation. The thousands of daily commercial operations without incident serve as testimony to the remarkable achievements made in aviation safety. But while standard instrumentation has served aviation well, trends in operations and accident statistics are showing disturbing forecasts. Human flight is far from the ancient ideal of visual, bird-like flight and aircraft accidents serve as powerful reminders of the dangers lurking whenever humans take to the skies.

The problems confronting modern aviation still involve limited visibility as a causal factor. For example, 30% of commercial aviation and 50% of all aviation fatalities are categorized as controlled-flight-into-terrain accidents. In general aviation (GA), almost three times more GA fatalities occurred in instrument meteorological conditions. Limited visibility also increases the potential for runway incursions that, from 2000 to 2003, averaged 5.6 runway incursions per million aircraft operations or 1,474 runway incursions out of 262 million aircraft operations. Finally, the most significant problem causing airport delays are limited runway capacity and the increased air traffic separation required when weather conditions fall below visual flight rules operations. Many of these visibility problems have much to do with how cognitively complex flying has become owing largely to the evolution of cockpit displays design, which require the pilot to extract and integrate information from multiple display sources to form a mental model. As a consequence, significant increases in aviation safety are unlikely to come from continued extrapolation from what exists today. As Theunissen (1997) observed, “new functionality and new technology cannot simply be layered onto previous design concepts because the current system complexities are already too high. Better human-machine interfaces require a fundamentally new approach” (p.7). Synthetic vision is one such new approach; it is a visibility solution to these visibility problems.

2. NASA Synthetic Vision System

The National Aeronautics and Space Administration (NASA) Aviation Safety and Security Program (AvSSP), Synthetic Vision Systems project is developing technologies that will mitigate low visibility as a causal factor to civil aircraft accidents while replicating operational benefits in unlimited ceiling and visibility day conditions, regardless of actual outside weather or visibility conditions. The goal is to augment pilot cognition and perception by creating a “virtual visual meteorological condition.” To achieve this, synthetic vision must encompass more than visual representation of the outside world presented on a two-dimensional cockpit display. Synthetic vision must be, instead, a system that incorporates four complementary elements that together extend pilot cognitive abilities, in any weather or visibility condition, which meet or exceed those during visual flight rules flight without the Synthetic Vision System. These four elements are an enhanced intuitive view, hazard detection and display, integrity monitoring and alerting, and precision navigation guidance.

2.1. Enhanced Intuitive View

Synthetic vision systems present an enhanced intuitive view by display of pertinent and critical features of the environment external to the aircraft through computer-generated imagery irrespective of weather conditions that may prevent a pilot from effectively seeing these factors through the cockpit window.

One method for providing an enhanced view is by intuitive design where the display format presents these “flight-critical” data in the way that the pilot normally would see in day visual meteorological conditions. This design format is used predominately within the tactical flight displays - the head-down primary flight display (PFD) and on the Head-Up Display (HUD) (Figure 1). In particular, since the HUD depiction is always conformal, the SVS provides an augmented reality display within the HUD field-of-regard, when forward outside visibility may be limited, but still operating under Visual Flight Rules. Further, SVS depicted on both the PFD and HUD provide for emergent details for more rapid and positive recognition and awareness, as visibility transitions from instrument to visual conditions.

The displays also include advanced symbology and guidance features that reduce flight technical error and foster instant recognition and awareness for the aircraft planned flight path. This information is generated by highway-in-the-sky guidance information on the tactical displays and three-dimensional route depictions on the strategic displays. Enhanced intuitive view further is achieved through advanced surface guidance map displays, which uplink ATC taxi clearances and graphically present the route and ATC instructions on a moving map display of the airport environment (Figure 1).



Figure 1. Synthetic Vision System Displays

The Synthetic Vision System is also designed to support enhanced intuitive strategic views by understanding how a pilot's informational needs differ from tactical flight operations. For example, synthetic vision navigation displays have significant potential to help a pilot's cognitive understanding of map and ownship positioning and that of traffic, terrain, and obstacle hazards (Figure 1). An innovative feature for the Synthetic Vision System navigation display has been developed to include a multi-mode navigation function that allows pilots to select between 2-D and 3-D exocentric views (Figure 2). Pilots normally use the 2-D synthetic vision co-planar navigation displays. With SVS displays, the pilot can initiate a "situation awareness" mode that presents several 3-D exocentric perspectives that time-out back to the normal 2-D co-planar SVS navigation display. The "situation awareness" mode also provides a dynamic "rehearsal" tool that pilots can use to step through and rehearse complex or unfamiliar airport approaches and non-normal procedures prior to initial descent or departure during a low workload phase of flight (Figure 3).

The culmination of SVS display technology is not just a visual cue analog of visual flight rules operations but, with these mentioned benefits, SVS will provide greater situational awareness than an aircraft operating in actual VMC.

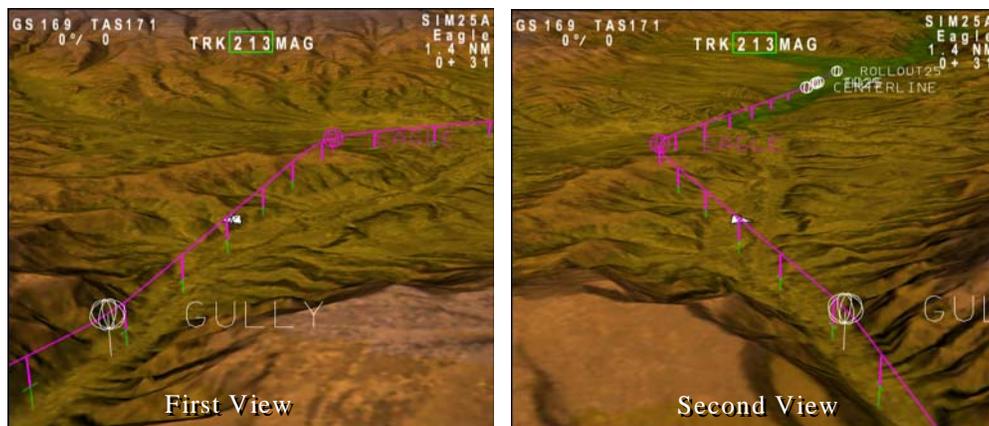


Figure 2. 3-D Exocentric Display Modes

2.2. Hazard Detection and Display

Terrain, cultural, traffic, obstacles, and other hazards are graphically represented to the pilot to maintain the pilot's situation awareness and proactively ensure terrain and hazard separation. The Synthetic Vision System provides for improved pilot detection, identification, geometry awareness, prioritization, action decision and assessment, and overall situation awareness not afforded by today's avionics. This allows the pilot to be proactive in avoiding hazardous conditions instead of reactive to alert cautions and warnings with traditional cockpit displays.



Figure 3. Situation Awareness Rehearsal Tool (shown here for rehearsal of missed approach)

Synthetic vision systems technology utilizes available sensor data to extract (automatically) traffic, terrain, and obstacle hazards and present these data – clearly and obviously – through icons or symbols to the flight crew. Currently, this processing is restricted to “known” hazards available in a database or through Notice-to-Airmen (NOTAM) information or transponding aircraft/vehicles. Eventually, this capability will grow to real-time imaging and non-imaging sensor processing technology whereby the information provided by infrared, milli-meter wave radar, and enhanced weather radars will be automatically processed and traffic, terrain, and obstacle hazards, not already contained in the SVS database, will be identified and shown on the displays. By using sensor image processing, the ability of the pilot to use, interpret, and understand sensor information, particularly sensor information outside of the normal visual wavelengths, would no longer be a determining factor for aviation safety using enhanced vision. The sensor/image processing will contain the necessary knowledge and information to perform this task. It will be unnecessary to conduct significant (and costly) pilot training to understand and use “enhanced vision” sensors.

Additionally, a runway incursion prevention system (RIPS) subsystem is operating as part of the SVS to alert the pilot to potential airborne or ground incursion aircraft or ground vehicles (Figure 4), as well as providing surface guidance and alerting to off-nominal conditions. In essence, RIPS provides an independent monitoring function for operations near and on the airport surface, to reduce the possibility of incidents or accidents caused by pilot errors or mistakes.

2.3. Integrity Monitoring and Alerting

Some level of integrity monitoring and alerting is required in all SVS applications because pilots must trust that the synthetic vision system provides an accurate portrayal (i.e., not hazardously misleading information). A flight-critical level of integrity, redundancy, and the inclusion of reversionary modes are needed to achieve the ultimate potential for a Synthetic Vision System. The Synthetic Vision System has independent sources to verify and validate the synthetic vision presentation (e.g., radar altimeters, enhanced vision sensors, TAWS, weather radar) fashioned to create integrity monitoring functions. If the integrity monitoring discovers a mismatch, the displays degrade gracefully to reversionary modes and trigger an alert to the pilot that synthetic vision is no longer available or reliable (Figure 5). The system effectively prevents a pilot from using erroneous or misleading synthetic vision information.

2.4. Precision Navigation Guidance

Synthetic Vision System features (e.g., surface guidance, taxi maps, tunnels/pathways/highways-in-the-sky, velocity vectors, command guidance cues) allow pilots to rapidly and accurately correlate ownship position to relevant terrain, desired flight paths/plans, cultural features, and obstacles. These elements enable the pilot to monitor navigation precision to meet Required Navigation Performance (RNP) criteria and compliance with complex approach and departure procedures (RNAV, GLS, curved, step-down, noise abatement) without the need for land-based navigation aids (e.g., ILS, VOR, DME, ADF, NDB, LORAN) that are expensive to install and maintain.



Figure 4. Runway Incursion Prevention System Alerting

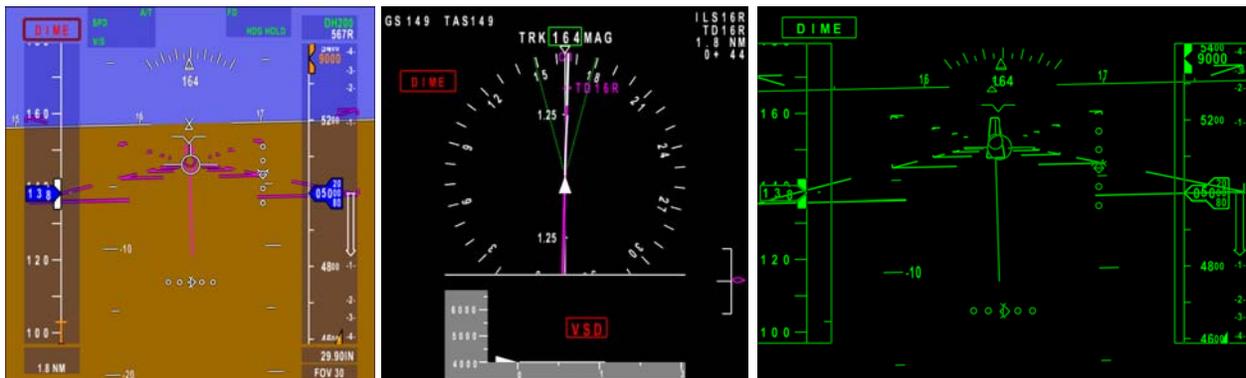


Figure 5. Database Integrity Monitoring Alert

There are several unique and innovative features of the Synthetic Vision System that support precision navigation guidance. First, the system uses a pathway-in-the-sky tunnel format that presents dynamic cues for instantaneous recognition of ownship positioning relative to the flight path. The tunnel depiction modulates based on flight path error in response to where the aircraft is positioned inside the flight path boundaries (Figure 6). If the pilot flies the aircraft outside these boundaries, tunnel cues help guide the pilot back into the tunnel. The tunnel is partnered with a flight path marker and (pursuit) guidance cue that enable the pilot to easily achieve RNP standards while significantly reducing workload and enhancing situation awareness. The pathway concept also provides 4-D visual guidance (speed channel symbology) to meet required time to arrival which help the pilot manage aircraft power inputs to more precisely arrive on time (Figure 7). Pathway guidance is also provided on the ground with symbology that helps the pilot manage ground speed, runway exit speed, braking, etc. (Figure 7).



Figure 6. Dynamic Pathway-In-The-Sky Tunnel



Figure 7. 4-D Tunnel (left figure) and Roll-Out And Take-Off Symbology (right figure)

3. Augmented Cognition through Synthetic Vision System Technology

The four elements of enhanced intuitive view, hazardous detection and display, integrity monitoring and alerting, and precision navigation guidance provide the necessary ingredients to augment pilot information processing.

Information processing can be represented simply as a four-stage sequential model. The first stage, or information acquisition, describes the acquisition and registration of sensory and perceptual inputs involving activation of sensory receptors, sensory processing, pre-processing of data prior to full perception, and orientation and selection of attended stimuli. The second stage, or information analysis, refers to active perception and information retrieval, encoding, and manipulation using working memory. Cognitive operations are active in this stage but occur prior to the point of decision, and involve processes of rehearsal, integration, and inference. The third stage, or decision and action selection, is where decisions are made based on cognitive processing. Finally, the fourth stage, or action implementation, occurs with the response or action consistent with the decision.

The four-stage model is a simplification of the richness of human information processing, but it does allow adoption for describing human-interaction with system functions (cf., Parasuraman, Sheridan, and Wickens, 2000) and helps to show how synthetic vision helps to achieve Augmented Cognition objectives. Below are examples of how the four Synthetic Vision System element technologies support each stage of human information processing to eliminate pilot information processing bottlenecks, limitations, and biases.

3.1. Information Acquisition

Information acquisition refers to the sensing and registration of inputs to the human sensory system. As stated in AFMAN 11-217, “Vision is by far the most important sensory system providing spatial orientation during flight.” Synthetic vision, with its enhanced intuitive view, strives to mitigate the lack of outside visibility through the intuitive presentation of references that orient the pilot to the outside world and the hazards to be avoided. These references provide both spatial orientation and geographic orientation information, both critical ingredients to ensure avoidance of Controlled-Flight-Into-Terrain.

3.2. Information Analysis

Information analysis involves higher cognitive functions that integrate incoming data to predict future states. In an aviation context, integration and prediction of the vast array of data is not often easy. Pilots often speak of the need to “stay ahead of the aircraft” that is necessary to achieve higher levels of situation awareness. During IMC, this requires the pilot to integrate symbolic and alphanumeric data information from separate cockpit displays to create a mental image or model of that world beyond his or her visual range. Synthetic vision, however, integrates multiple sources of data and presents this flight information in an intuitive visual way, greatly adding to the pilot’s information analysis task.

The Synthetic Vision System technology embraces specific features to enhance a pilot’s information analysis by including, for example, intuitive planned flight path displays using pathway-in-the-sky or tunnel displays, geographical and conformal flight hazard information using synthetic terrain and enhanced / synthetic vision object fusion, and future path/prediction information via multiple-mode exocentric 2-D and 3-D navigation display capability, trend predictors, runway exit speed guidance, etc.

3.3. Decision and Action Selection

Decision and action selection refers to a selection among decision alternatives based on information analysis of input data. For cockpit display systems, decision and action selection would be supported through display alerting that provides a solution set of alternative actions for the pilot to choose from. Synthetic vision technology creates decision and action alternatives where none existed previously. When an enhanced ground proximity warning system alert occurs, in the absence of synthetic vision, the pilot's action is constrained to vertical maneuver only, because insufficient information is provided for lateral maneuvering. Information on whether this action is the best or proper decision is non-existent. The Synthetic Vision System provides the pilot with the information necessary for prioritization of significant threats and determination of immediacy and proximity of closed point of approach through integration with associated aircraft systems and graphical presentation. The system also supports decision-making to which action, if any, is appropriate with regard to aircraft maneuvering or communication to maintain safe separation from hazards.

Another example involves real-time detection of hazards, obstacles, runway, other aircraft, etc. and represents that information to the pilot. If a conflict exists, the system alerts the pilot and orients them to the hazard with specific information as to nature of the threat, proximity, and threat significance. The information is displayed in real-time so closure rates and proximity can be assessed for the pilot to select the best course of action, given their experience, understanding of the aircraft systems state and performance, and training, rather than rote procedures.

3.4. Action Implementation

Action implementation applies to actual execution of the action selected. An example would be the automatic ground collision avoidance system (auto-GCAS) that could automatically maneuver an aircraft for terrain avoidance.

The Synthetic Vision System was designed principally to support manual flight operations, and to develop provisions which may complement and do not restrict automatic flight. In this sense, SVS technology provides the pilot with sufficient information relating to relative success of maneuver decided upon for achieving design goal of maintaining safe operation. This includes further iteration of action decision, action implementation, and feedback.

4. Synthetic Vision System as Modulator of Information Processing in Real-World Environments

The Synthetic Vision System shares many commonalities with other AugCog technologies. The present paper has described how the technology supports pilot information processing through system elements of enhanced intuitive view, hazardous detection and display, integrity monitoring and alerting, and precision navigation guidance. These elements provide for global situation awareness of threats and future projection of path control decisions through display presentation, integrated hazard alerting, dedicated image object detection and fusion computation equipment, traffic and obstacle presentation, integrity monitoring, and other features of the Synthetic Vision System. The enhancement of local guidance and global situation awareness supported through augmentation of human information processing has significant safety and operational benefits.

The following sections present an overview of selected flight test research that illustrates the Synthetic Vision System as modulator of information processing in real-world environments. The pay-off from improved information processing by SVS for commercial aviation consists of safety and operational benefits that are described below. (Synthetic Vision System technology has also been employed for general aviation use, and demonstrated the efficacy of the technology to significantly extend pilots capabilities and mitigate low visibility as a causal factor in general aviation accidents (cf., Prinzel et al., 2004). These works are not, however, discussed here.)

4.1. Terrain-Challenged Commercial Aviation Operations

Flight test evaluations were conducted to test the efficacy of the Synthetic Vision System in and around terrain-challenged airport environments. These locations were chosen because of the significant high terrain that surrounds each of these airports and the complex operational procedures needed to ensure terrain separation. A primary goal of these flight tests was to demonstrate that manually flown approaches into these airports could be done safer and more efficiently than with today's instrumentation.

4.1.1. Eagle, Co. Regional Airport (EGE) Flight Test (2001)

The objective of the Eagle-Vail, CO (EGE) flight test was to demonstrate the operational and safety benefits of

synthetic vision display technology in a terrain-challenged operating environment. Flight test evaluations of tactical display concepts were conducted over a three-week period. Seven evaluation pilots, representing Boeing, Delta, United, American, the FAA and NASA, participated in testing to evaluate pilot acceptability/usability and terrain awareness benefits of head-down and head-up primary flight displays. Predominately using existing approach and departure procedures (Figure 8), synthetic vision display configurations were evaluated consisting of several NASA terrain texturing and display size concepts. In total, 106 approaches and departures were conducted for data. The details of the EGE flight test are described in Kramer et al. (2004).

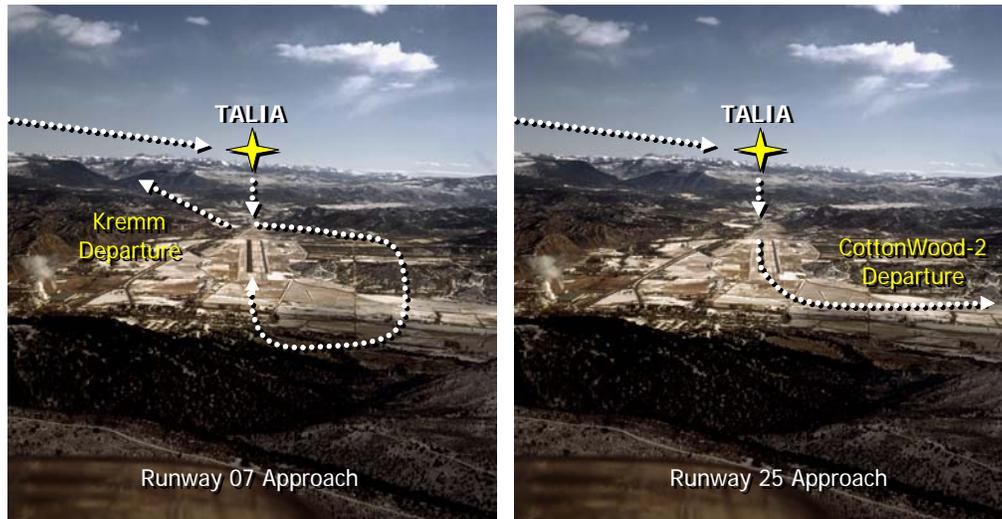


Figure 8. EGE Approach and Departure Experimental Tasks

4.1.2. Reno/Tahoe International Airport (RNO) / Wallops Flight Facility (WAL) (2004)

The objective of the Reno, NV and Wallops, VA flight test, known as GVSITE, was to evaluate the performance, usability, and acceptance of an integrated synthetic vision concept, which included advanced Synthetic Vision display concepts (Figures 9) for a transport aircraft flight deck, a Runway Incursion Prevention System (RIPS), Synthetic Vision and Enhanced Vision sensors, and real-time Database Integrity Monitoring Equipment (DIME). Fifty-nine flights were flown over a 66-day period at the Reno-Tahoe International Airport (RNO) and at NASA's Wallops Flight Facility (WAL). Over 129 flight hours were flown with 166 landings and 186 low approaches, in daylight and night conditions. The flights included Runway Incursion scenarios using NASA's Be-200 aircraft and SV-Sensors Radar Van, used to test the integration of Synthetic Vision System with the RIPS. The flight test also included the evaluation of various DIME operational scenarios and SV-Sensors performance on the Gulfstream-V aircraft. The flight test marked the first time NASA's technologies have been integrated as a complete system incorporating advanced weather radar object detection, synthetic vision database integrity monitoring, refined dynamic tunnel and guidance concepts, and RIPS. The details of the RNO/WAL flight test are described in Kramer et al. (in press).



Figure 9. Flight Testing Integrated Synthetic Vision System

The flight test results showed statistically significant improvements in pilot's situation awareness, lower workload, and reduced flight technical error when using the synthetic vision display concepts compared to approaches with current instrumentation. In addition, pilots were able to fly a complex visual arrival and non-normal departure procedures using the SVS in simulated IMC.

In terms of safety benefits, these flight tests showed that synthetic vision may help to reduce many accident precursors including:

- Loss of vertical and lateral path, terrain and traffic awareness
- Unclear escape or go-around path even after recognition of problem
- Loss of altitude awareness
- Loss of situation awareness relating to the runway environment and incursions
- Unclear path guidance on the surface
- Transition from instruments to visual flight and spatial disorientation

These safety benefits are particularly evident during non-normal and emergency situations. In these non-normal events, mental workload and tasking/attentional demands placed on the pilot are high and synthetic vision systems, through their intuitive display and presentation methods, off-load the pilots from basic spatial awareness tasking (to avoid terrain, traffic, and obstacles), increase their speed of situation recognition, and provide resolution recovery guidance.

4.2. Operationally-Complex Commercial Aviation Operations

The aviation safety benefits alone may be reason enough to pursue the technology, but operational and economic benefits must be considered for Part 121 and 135 operations because of the costs associated with implementation of these systems. A NASA-sponsored cost-benefit analysis of 10 major US airports calculated the average cost savings to airlines for the years 2006 to 2015 to be \$2.25 Billion. While these savings are predicated on several technology developments and successful implementation/certification, there is a potential order of magnitude in economic savings and operational efficiency that can be achieved. These benefits, however, must be shown through operational demonstration that pilot information processing can best be supported using this technology because it allows for flight operations that otherwise would not be possible with traditional instrumentation.

5.2.1. Dallas Fort-Worth (DFW) Airport (2000)

The objectives of the Dallas Fort-Worth (DFW) flight test were: (1) to evaluate to the potential of retrofitting SVS technology into current flight decks and as a forward-fit technology into future flight deck concepts and (2) to evaluate an aircraft-based RIPS integrated with a FAA Runway Incursion Reduction Program surface infrastructure (Figure 10). The flight test evaluated the technical and operational system performance of synthetic vision displays, airport surface databases and runway incursion warning systems suitable for retrofit into current technology cockpits using complex, side-step runway maneuvers during nighttime operations. Ten evaluation pilots performed 122 test runs (approaches and surface operations) using NASA's Boeing 757 research aircraft at night in an operationally challenged, international airport environment. The details of the DFW flight test are described in Prinzel et al. (2004).



Figure 10. Dallas Fort-Worth Nighttime Operations

In terms of operational benefits, this flight test and others showed synthetic vision could serve to increase National Airspace System capacity by providing the potential for increased visual-like operations gate-to-gate even under extreme visibility restricted weather conditions (e.g., Category IIIb minimums), including:

- Intuitive depiction of ATC cleared flight paths and taxi clearances
- Enhanced surface operations (e.g., rollout, turn off and hold short, taxi)
- Reduced runway occupancy time in low visibility
- Reduced departure and arrival minimums
- Better allow for converging and circling approaches, especially for dual and triple runway configurations
- Provide for independent operations on closely-spaced parallel runways
- Provide for precise noise abatement operations
- Required Navigation Performance adherence and 4D navigation potential
- Enhanced path guidance, compliance monitoring, and alerting, and enhanced flight management
- Depiction of terminal, restricted and special use airspace
- Depiction of traffic and weather hazards and resolutions
- Approach operations to Type I and non-ILS runways
- Piloting aid support (e.g., flare guidance, runway remaining, navigation guidance)

6. Conclusions

Augmented Cognition refers to computational technologies designed to explicitly address human information processing bottlenecks, limitations, and biases. Synthetic vision can be considered an emerging AugCog technology that increases a pilot's perceptual and cognitive capabilities, resulting in enhanced situation awareness, visualization capabilities, and attention to help meet national aviation goals of reducing the fatal accident rate and improving National Airspace System efficiency and throughput. The paper described the four elements of the Synthetic Vision System and discussed how the technology supports AugCog objectives demonstrated through real-world flight test evaluations. New directions will develop prevention, intervention, and mitigation technologies integrated with the Synthetic Vision System to help address the safety and security needs of the National Airspace System. The future system will further embed AugCog-type technologies and continue to support the human user and enhance human performance, interaction and reliability in the use and design of these complex aerospace systems.

7. References

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