Technical Challenges In the Development of a NASA Synthetic Vision System Concept

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ABSTRACT

Within NASA's Aviation Safety Program, the Synthetic Vision Systems Project is developing display system concepts to improve pilot terrain/situation awareness by providing a perspective synthetic view of the outside world through an on-board database driven by precise aircraft positioning information updating via Global Positioning System-based data. This work is aimed at eliminating visibility-induced errors and low visibility conditions as a causal factor to civil aircraft accidents, as well as replicating the operational benefits of clear day flight operations regardless of the actual outside visibility condition. Synthetic vision research and development activities at NASA Langley Research Center are focused around a series of ground simulation and flight test experiments designed to evaluate, investigate, and assess the technology which can lead to operational and certified synthetic vision systems. The technical challenges that have been encountered and that are anticipated in this research and development activity are summarized.

INTRODUCTION

Limited visibility has been cited as the "single greatest contributing factor in controlled-flight-into-terrain accidents, general aviation accidents, and airspace capacity limitations." In commercial aviation alone, over 30% of all fatal accidents worldwide are categorized as Controlled Flight Into Terrain (CFIT), where a mechanically sound, normal functioning airplane is inadvertently flown into the ground, water, or an obstacle, principally due to the lack of outside visual reference and situational awareness (Reference 1). Airspace capacity drops dramatically with loss of visibility in terminal operations. The Synthetic Vision Systems (SVS) Project, under NASA's Aviation Safety Program (AvSP), is developing technologies with practical applications that will eliminate low visibility conditions as a causal factor to civil aircraft accidents while replicating the operational benefits of clear-day flight operations, regardless of the actual outside visibility condition (Reference 2).

Synthetic Vision Display Concepts

NASA's SVS tactical display concept provides a real-time, unobscured synthetic view of the world for the pilot. The display concept, illustrated in Figure 1, is generated by visually rendering an on-board terrain database (with airport and obstacle database information) using precise position and navigation data obtained through GPS (Global Positioning System) data, with augmentation possibly from differential correction sources such as Local Area Augmentation Systems (LAAS) and/or Wide Area Augmentation Systems (WAAS) blended with on-board Inertial Navigation System (INS) information. The accuracy and integrity of the synthetic vision display is ensured by onboard sensors for integrity monitoring (such as multi-mode weather radar and high quality radar altimeters, Reference 3). Further, traffic, obstacles, and other flight hazards are sensed by appropriate on-board sensors and/or datalink, and rendered on the synthetic display to augment the stored database with flight-critical real-time information.

Numerous research and development activities are on-going to develop the technologies integral to this synthetic vision display system concept. These activities are centered around a series of ground simulation and flight test experiments fashioned to evaluate, investigate, and assess the technology.

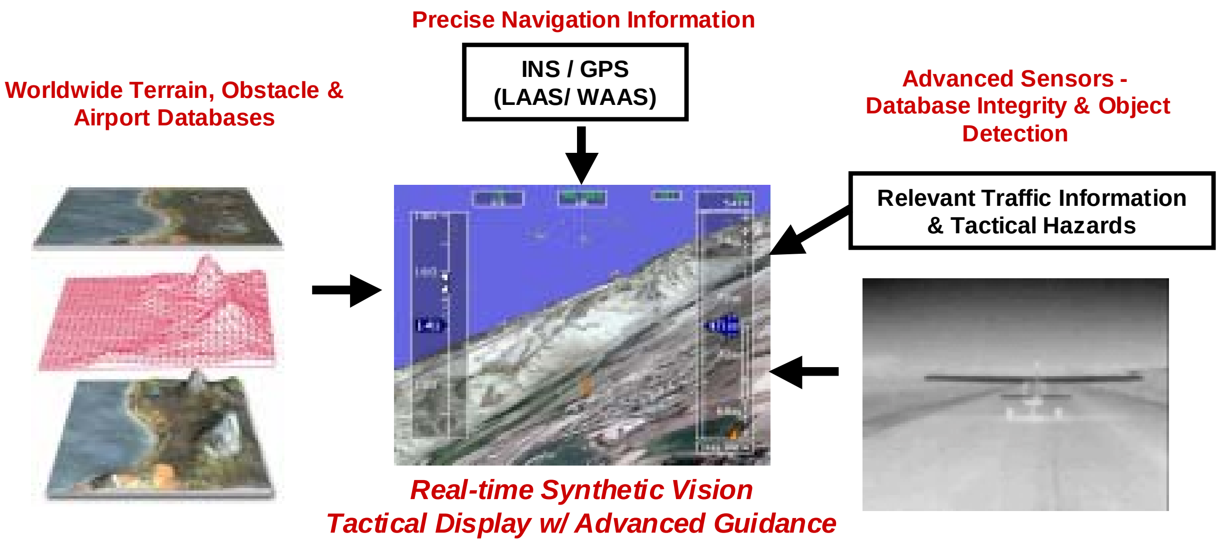

Figure 1: SYNTHETIC VISION SYSTEM CONCEPT

Program Plans and Flight Test

The NASA Synthetic Vision Systems Project started in Fiscal Year (FY) 2000 and is scheduled to continue through FY2005. A "waterfall" research and development program was established in the beginning of the program to tackle the projected high-risk challenges and develop the associated technologies to a technology readiness level of 6. NASA's SVS activities have been parsed into three program elements: Enabling Technologies, General Aviation, and Commercial and Business Aircraft. Several Cooperative Research Agreements (CRA) have been established with industry and academia to assist in technology development.

To date, two major NASA flight tests have occurred for assessment and evaluation of the SVS developments for the Commercial and Business Aircraft element. Both flight tests have used the NASA/Langley Research Center (LaRC) 757 Airborne Research Integrated Experiments System (ARIES) – a modified Boeing 757-200 jetliner (Figure 2). The first flight test was flown Sept-Oct 2000 in the vicinity of Dallas-Ft. Worth International Airport (FAA Identifier: DFW). The second flight test was flown Aug-Sept 2001 in the vicinity of Eagle County Regional Airport, CO (FAA Identifier: EGE). A third flight test, the Initial SVS Integrated Technology Evaluation (InSITE) flight test, is currently in the planning stages. This flight test is scheduled to begin June 2003 in the local area around NASA/Langley, followed by a deployment to Reno/Tahoe International Airport (FAA Identifier: RNO) for operationally-oriented evaluations, in a terrain-challenged airport area.

The SVS flight tests to date (DFW/2000 and EGE/2001) have primarily focused on the general use and usefulness of SVS for providing flight critical guidance and improved situational awareness. The research objectives of these previous flight tests emphasized subsystem aspects of the SVS display (e.g., size, content, and format) and on SVS enabling technologies (e.g., Runway Incursion Prevention System, RIPS; Enhanced Vision System, EVS; and database integrity monitoring experiment, DIME).

The InSITE flight test will evaluate, for the first time, the integration of SVS technologies into the overall SVS concept design, with such a design hopefully being representative of a viable commercial air transport product. While differential GPS (D-GPS) and on-board databases can provide the primary framework for an operational SVS, independent integrity monitors for both surveillance and navigational functions will likely be necessary to meet certification and safety requirements. Specifically, on-board integrity sensors will provide independent air-to-air, air-to-ground, ground-to-ground, and ground-to-air traffic and object surveillance, a runway incursion monitor, and a confirmation of database integrity and registration (navigational position confirmation via terrain feature extraction). Additionally, the requirements for augmenting SVS concepts with the independent capabilities of weather-penetrating, enhanced vision imaging sensors during low visibility landing and surface operations conditions will be explored. These technologies form the basis for monitoring the dynamic flight environment and thereby, supplementing the synthetic world with real-time, direct measurement of the surrounding terrain and air/ground traffic.

Figure 2: NASA/LaRC's BOEING 757 ARIES

DISPLAY CONCEPT DEVELOPMENT

The development of the SVS display concept has primarily tackled the challenges associated with display media and synthetic vision display content requirements.

Display Media Type

A major thrust of the SVS Project involves the development and demonstration of affordable, certifiable display configurations for Commercial and Business (CaB) aircraft. Significant effort has been planned into the "retrofit" issues associated with this advanced display technology since to measurably impact safety and operations, a majority of the fleet has to be affected to make a positive impact.

The retrofit issue thrust first focused upon the compatibility of existing cockpits and cockpit displays to host synthetic vision upgrades. As indicated by the data in Figure 3, the actual and projected world-wide fleet of jet aircraft shows that the majority of jet transports are now and will remain those equipped with "glass" cockpits (Reference 4-5). While this data might at first be encouraging, retrofit is still a formidable challenge. While "glass" displays may be installed, the display drivers, graphics drivers, and drawing capability necessary to host a synthetic vision display system are not necessarily available (Reference 6).

HUD Retrofit Potential

Although exact marketing statistics are not available, an obvious commercial airline market trend is the tremendous growth in the installation of Head-Up Displays (HUDs), thanks to the operational benefits granted by an installed Head-Up Guidance (HGS) system (Reference 7). With this trend, a cost-effective retrofit path for SVS in HUD-equipped aircraft may be possible by generation of a synthetic vision image as the raster input source to a stroke-on-raster HUD (Figure 4). This display concept is analogous in many respects to the Enhanced Vision System (EVS) certified on the Gulfstream V, except that the raster image is synthetically-derived rather than being a direct imaging sensor output. Unlike EVS displays, the synthetic vision-HUD (SV-HUD) concept uses a clear sky rather than a sensor image of the sky, so there is no obstruction of that area of the display. Below the horizon, the raster image may obstruct the view of the outside real world (as with an EVS image), particularly if the raster brightness is not controlled appropriately by the pilot. Obstruction of the outside real world scene by such a display is a recognized certification issue.

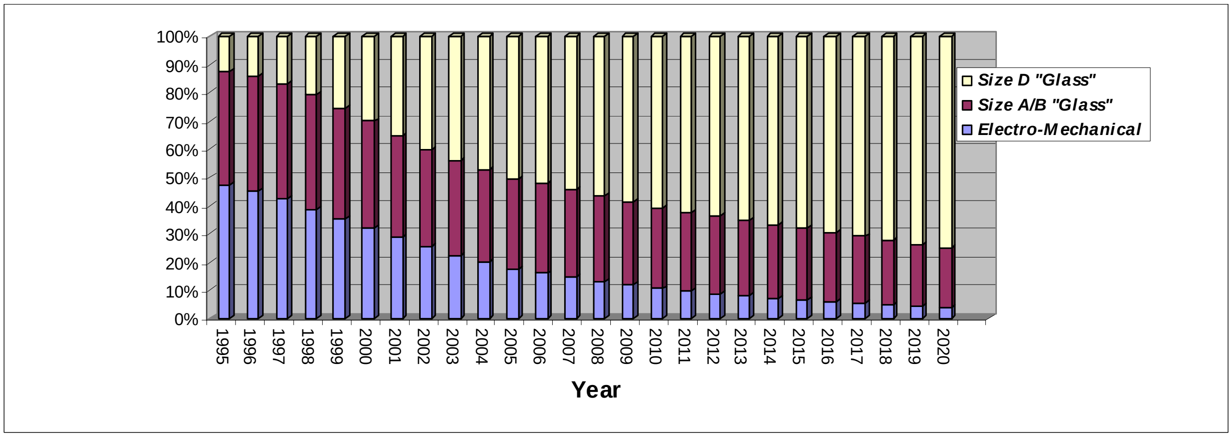

Figure 3: **PERCENTAGE OF WORLD JET TRANSPORT AIRCRAFT COCKPIT DISPLAY EQUIPAGE**

The viability of the SV-HUD was initially tested and "proven" in the DFW flight trials. Flying night, Visual Flight Rules (VFR) operations, the colliminated HUD imagery provided immersive qualities which were very well-received by the evaluation pilots. Pilot comments noted positive situation awareness benefits without significant liabilities. Separate HUD controls for the stroke and raster brightness and a button on the control yoke for symbology and (SV) raster imagery declutter were essential.

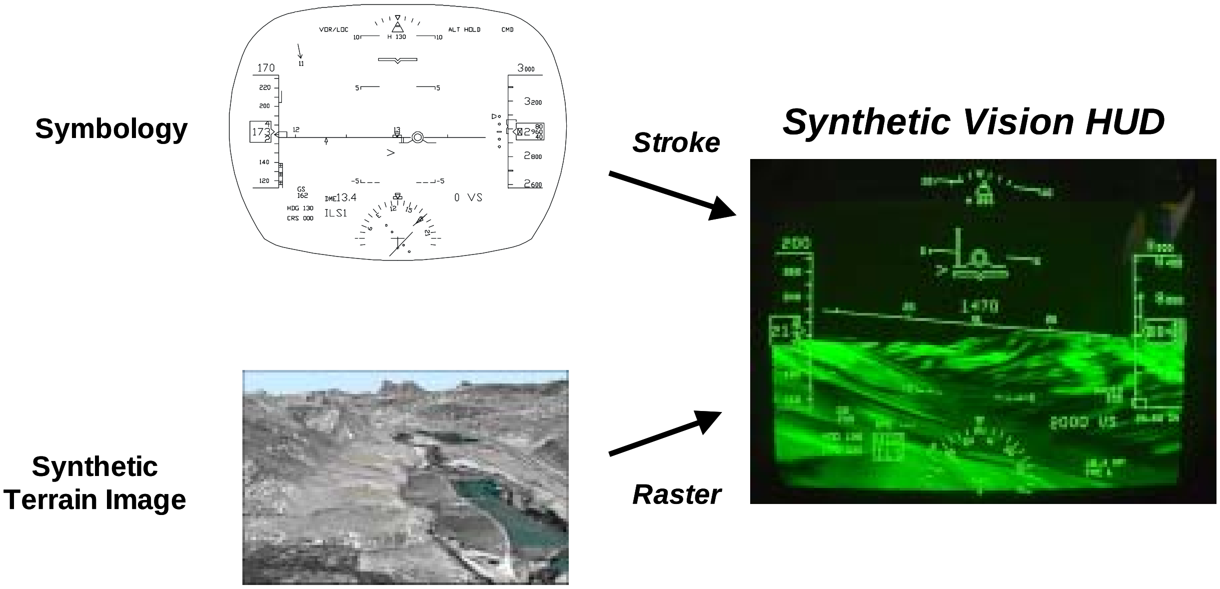

Figure 4: **SYNTHETIC VISION HUD CONCEPT**

During the EGE flight trials, the SV-HUD concept was, again, proven to be an enhancement over present-day cockpit display technology for terrain awareness. In the EGE flight test, comparisons were made against a baseline display suite consisting of a Size A Electronic Attitude Direction Indicator (EADI) and a Size B Navigation Display (ND), including Terrain Awareness and Warning System (TAWS) capability. As shown in Figure 5, a majority of evaluation pilots subjectively rated their awareness of the terrain as being better when flying the SV-HUD than when flying the baseline display suite.

In both flight trials, the SV-HUD concept was, for all intents, a monochromatic green representation of the full-color, head-down display SV concept, using an RS-343 video format. No effort was expended to examine graphical light source or other terrain shading issues.

In contrast to the subjectively-reported success, however, the data of Figure 5 also shows that the situation awareness enhancement was not universal. Some negative ratings (similar to the baseline display suite) were given because of two significant deficiencies: illegible display renditions under some direct sunlight conditions and some reported terrain depiction illusions. HUD luminance and contrast requirements are being developed, as highlighted below, for SV-HUD applications. The problem of terrain depiction illusions and a technique for their potential elimination are also discussed below.

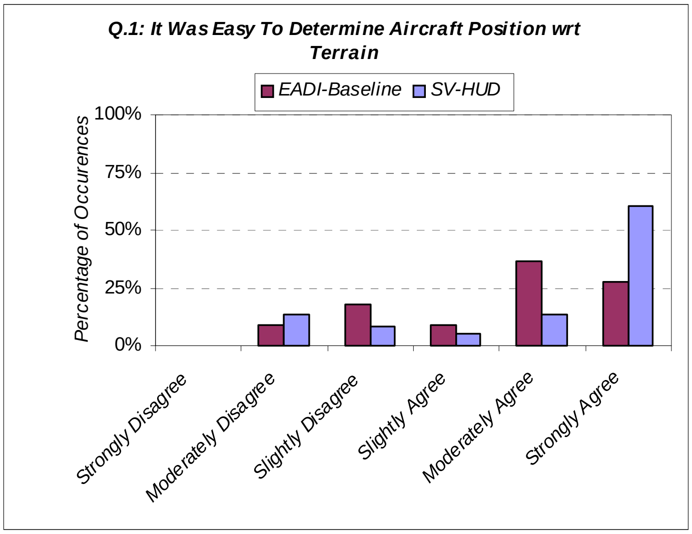

Figure 5: TERRAIN AWARENESS OF SV-HUD VS. EADI & TAWS BASELINE DISPLAY SUITE.

HUD Luminance Capabilities

According to the Society of Automotive Engineers (SAE) Aerospace Recommended Practice (ARP) for Transport Category Airplane Head-Up Display Systems (ARP 5288), HUD luminance must be sufficient for generation of "a usable display under all foreseeable ambient background conditions, including a sunlit cloud of 34,000 cd/m^2 (10,000 fL)..." However, for HUD raster luminance, the vendor will specify the maximum background luminance operating conditions and the minimum of gray shades.

Pilot comments from the EGE flight trials indicated that there were instances where the sun angle washed out the SV HUD image and rendered the SV image unusable. To achieve the benefits of SV using the HUD, the SV raster image must be legible and useable in all foreseeable ambient background conditions. A "useable display" can be defined using many different figures of merit, but in the case of the raster HUD, Shades of Gray (SOG) has been specified as the figure of merit. Shades of Gray (SOG) are a measure of the HUD luminance dynamic range (Reference 8) where each Shade of Gray corresponds to a change in display luminance that differs by the square root of two. SOG can be equated to contrast ratio where contrast ratio (C_R) is defined by the ratio of the sum of the display-generated and ambient background luminance to the display-generated luminance by: $SOG = \log(C_R)/\log(\sqrt{2})+1$

Using a range of ambient lighting conditions, the contrast ratios for various combinations of ambient and HUD-generated luminance values are presented in Table I. The HUD-generated luminance values span typical stroke and raster luminance levels with today's technology: stroke luminance levels typically ranging from 2000 to 4000 ftL; raster luminance values between 1000 and 2000 ftL.

For SV-HUD applications, the available display contrast ratio must be considered in the development of the raster image source.

HUD Imagery Requirements for Synthetic Vision

In Army aviation applications (Reference 8), a minimum of 6 SOG is typically specified for adequate rendering of video imagery. 6 SOGs is equal to a contrast ratio of 5.66.

Other experimental data (Reference 9), using a simulated EVS image on the HUD, has indicated that lower contrast ratios (and SOG) may be acceptable depending upon the scene familiarity and expectations of the pilot. Contrast ratios as low as 1.45 (2.07 SOG) were acceptable for discrimination of a HUD/EVS airport raster image but contrast ratios of at least 2.50 (3.64 SOG) were necessary for discrimination of more general terrain imagery.

Contrast ratios of 1.15 are generally required as the minimum level for stroke symbology legibility.

Table I
Contrast Ratio Given Ambient and HUD Luminance Values

Ambient Brightness (ftL)	Ambient Brightness At Eye (ftL)*	Luminance - HUD (ftL) at Eye						
		4000	**3500**	**3000**	**2500**	**2000**	**1500**	**1000**
10000	6000	1.67	1.58	1.50	1.42	1.33	1.25	1.17
5000	3000	2.33	2.17	2.00	1.83	1.67	1.50	1.33
4000	2400	2.67	2.46	2.25	2.04	1.83	1.63	1.42
2000	1200	4.33	3.92	3.50	3.08	2.67	2.25	1.83
1000	600	7.67	6.83	6.00	5.17	4.33	3.50	2.67
500	300	14.33	12.67	11.00	9.33	7.67	6.00	4.33
100	60	67.67	59.33	51.00	42.67	34.33	26.00	17.67

* Assuming 75% Canopy and 80% Spherical HUD Combiner Transmissivity

These data would collectively suggest that the available HUD luminance (and resultant contrast ratios) will dictate the imagery content characteristics for SV-HUD applications. For example, the following guidelines are proposed:

- When HUD contrast ratios greater than 5.66 are available, the full dynamic range of SV imagery content should be useable and a monochromatic rendering of terrain imagery such as that used during the DFW and EGE flight trials should be legible.

- When HUD contrast ratios greater than 2.5 but less than 5.66 are available, the full dynamic range of SV imagery content may not be useable and a monochromatic rendering of terrain imagery needs to be evaluated and enhanced as necessary. Some negative pilot comments during the EGE flight evaluations were associated with visual artifacts in viewing the terrain portrayal in the monochromatic HUD even when the HUD raster image was legible. The pilots noted that several important features of the terrain, such as notches or rock outcroppings, were virtually invisible in the

HUD image. Post-flight evaluation showed that the raster image didn't contain sufficient dynamic range for correct pilot interpretation.

- When HUD contrast ratios greater than 1.45 but less than 2.5 are available, only imagery containing expected or easily distinguishable objects and/or patterns will be legible. High contrast imagery will be necessary.

- When HUD contrast ratios of only 1.45 or less are available, only high contrast lines will be legible (such as stroke written symbols).

Assuming today's raster HUD luminance capability (i.e., <2000 ftL), uncompromised rendering of the synthetic vision imagery (i.e., contrast ratios > 5.66) occurs only below ambient brightness levels of approximately 1000 ftL (e.g., night and dark Instrument Meteorological Conditions (IMC)) as shown in Table I. The excellent pilot acceptance of the SV-HUD from the DFW flight trials was enabled by the night conditions of this test.

For all other lighting conditions, terrain rendering methods must be tailored to match currently-available HUD technology luminance levels.

Some pilots in the EGE flight test reported an occasional inversion illusion with the synthetic terrain HUD image, in that, at one particular point, they would interpret a valley as a ridge, and a ridge as a valley. Post-flight image evaluations and experimentation with graphic light source sun angles while generating the monochrome terrain database seemed to eliminate the problem (see Figure 6). The attitude angle of the light source was changed from the default value of 45 degrees, to 67 degrees in the database image renderer. For mountainous terrain, 67 degrees seemed to be a good compromise between providing some relief shading while allowing enough light to clearly distinguish ridges

Rockwell-Collins, a NASA CRA partner, is employing a fish-net (a grid presentation of the terrain) for their synthetic vision HUD concepts. The fish-net or grid presentation is a high-contrast raster image which should be legible throughout all ambient background luminance ranges since it mimics stroke-written symbology. Rockwell-Collins testing has also developed methods to ameliorate one of the past problems with fish-net type displays – the annoying and distracting bright area caused by the confluence of edge lines in valleys or vanishing points. The USAF has found an Air Force pilot preference for the fish-net or grid format (Reference 10), especially when used in combination with an EVS image (Reference 11).

Direct comparisons between a fish-net and synthetic terrain HUD format were not conducted, but future NASA efforts are being directed at evaluating a fish-net terrain overlay embedded within synthetic vision terrain renditions. This approach is analogous to a fish-net synthetic terrain image combined with EVS. The theory is that the high contrast fish-net depiction will be noticeable and readable during all ambient lighting conditions, yet in lower ambient lighting conditions, the synthetic vision terrain depiction will be viewable to provide a high fidelity, unambiguous scene for terrain and obstacle awareness. Experimental data and other research (e.g., Reference 12) to support the definition of minimum acceptable luminance capabilities and scene content characteristics for SV-HUD concepts are planned for the coming years.

Terrain Awareness – SV-HDD Concept

While positive, but somewhat compromised results have been found for the SV-HUD concept (due to the monochromatic, limited luminance HUD capabilities) at EGE, statistically-significant benefits for the display of Synthetic Vision on Head-Down Displays (SV-HDD) have been found over a baseline display suite consisting of an EFIS with TAWS display configuration. The subjective rating comparison is shown in Figure 7 for the Size A/B SV-HDD concept and for the Size X SV-HDD concept compared to the baseline display configuration. The data clearly show a trend that the EP's "Strongly Agreed" that it was easy to determine the aircraft position with respect to terrain with a SV-HDD concept, particularly when implemented using the largest display media (Size X). The Size A photo-realistic and Size X generic and photo-realistic SV display concepts provided statistically-significant terrain awareness improvement over the baseline display (EADI and TAWS ND), F(6,73)=2.69, $p<0.01$.

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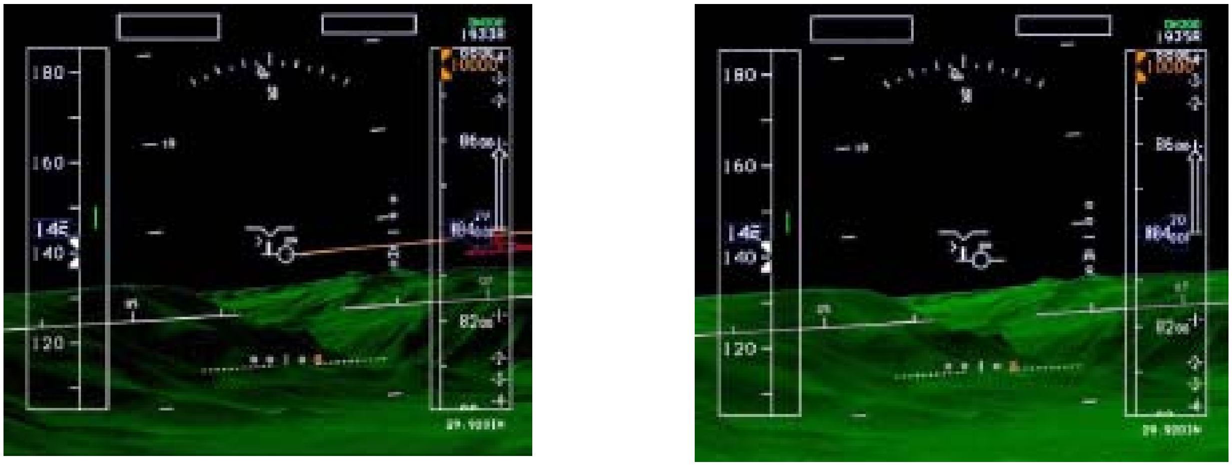


Old Scene

New Scene

Figure 6: HUD LIGHTING SOURCE COMPARISON

Display Size & Field-of-View Control

At the DFW flight trials, particular attention was given to whether Synthetic Vision concepts could effectively be implemented on common display sizes, down to ARINC Size A. Research to date has shown that display size is not a critical issue, given that field-of-view (i.e., field-of-regard) control is provided to the pilot (Reference 13).

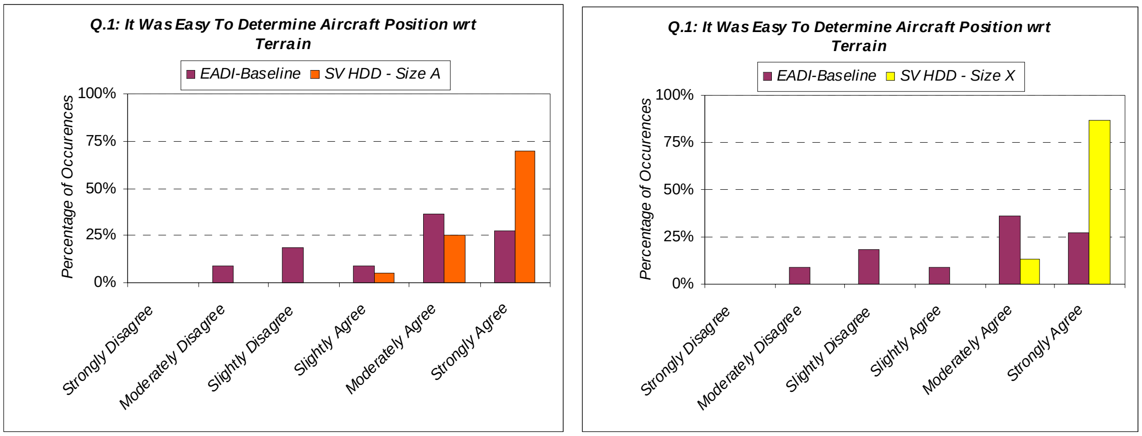


Figure 7: TERRAIN AWARENESS COMPARISON BETWEEN BASELINE AND SV-HDD

From the DFW flight trials, which involved a runway change task at 5 nm from touchdown, a consistent pattern was developed by the evaluation pilots for SV field-of-view control during the horseshoe approach course. During maneuvering from one extended runway centerline to another (e.g., the "transition" phase of a runway change task), larger field-of-view settings were generally used, with a gradual reduction in the field-of-view selection as the pilots neared the landing runway (e.g., the "tracking" phase of a runway change task). This behavior is interpreted as a function of display magnification (or in this case, display minification) in Figure 8, which shows the mean (and standard deviation) of the display minification factor used in the DFW runway change task plotted as a function of the SV-HDD size. The pilots tended to use a less minified display for the larger display sizes, but the minification factor always approached unity as the pilots neared landing for all display sizes (i.e., the "Tracking Phase").

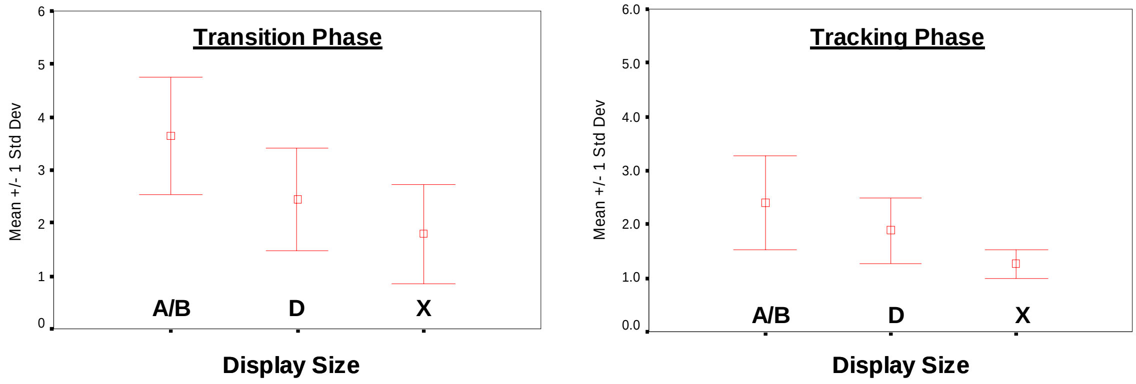


Figure 8: **SV DISPLAY MINIFICATION FACTOR - DFW RUNWAY CHANGE TASK**

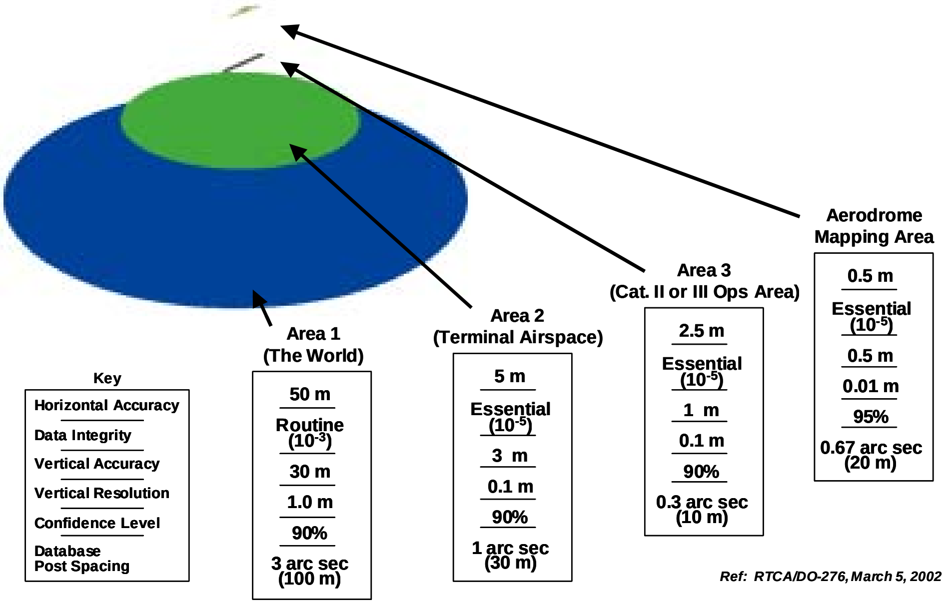
In the DFW flight trials, a touch screen was used for 5 degree incremental control of the field-of-view from unity magnification up to 120 degrees. At the EGE flight trials, the field-of-view control for the NASA SV-HDDs was simplified and improved. Touch screen control was found to be problematic (reach limitations and arm interference with a touch screen directly in front of the pilot). Instead, a four position wafer selection switch was implemented on a center console panel. The field-of-view options were “unity”, 30 deg, 60 deg, and 90 deg. This implementation was well-received but further improvement is being defined for the InSITE flight trials by using a voice recognition system as the primary pilot-vehicle interface.

DISPLAY CONTENT

Real-time rendering and database storage are two issues facing avionics manufacturers to successfully implement synthetic vision; thus, the SV design characteristics which affect these factors have been the subject of several studies.

The NASA SV display concepts used in flight were generated by a dual 866 MHz processor personal computer (PC) with 1^+ Gigabytes of Random Access Memory running Windows NT™ and a Wildcat™ 4210 graphics card to provide 1280 by 1024 anti-aliased video rendering at real-time (>30 Hz) update rates. This PC implementation proved that it is no longer a technical challenge to render these displays; unfortunately, the problem is rendering these displays using avionics-grade hardware. 3-D chip sets and computer architectures to support the graphics demands of SVS are being contemplated and built, but the industry is rapidly approaching the point, if it is not already there, that the pilot's cell phone has more computing power and graphics capabilities than the on-board aircraft avionics. This scenario cannot be an attractive aircraft marketing perspective.

Graphics rendering is not the only computational hurdle. Database storage issues have been historical concerns. For a one degree by one degree cell of database containing Digital Elevation Model (DEM) only, (approximately 60 sq. miles at the equator), the space required to store DTED Level 1 data (approx. 100 meter post spacing) is only 5 Megabytes, DTED Level 2 data (approximately 30 meter post spacing) 54 Megabytes, but DTED Level 4 (3 meter post spacing) is 6.3 Gigabytes. User requirements for Terrain and Obstacle Data (RTCA/DO-276, Reference 14) have been prepared which defined flight phase-dependent database resolution requirements and should help to mitigate database storage concerns while yet meeting the database accuracy required for precise navigation where needed (Figure 9).



Ref: RTCA/DO-276, March 5, 2002

Figure 9: RTCA-276 TERRAIN AND OBSTACLE DATABASE REQUIREMENTS OVERVIEW

To date, NASA SVS-CaB applications have nominally used 1 and 3 arc-second DEM. For instance, the EGE flight trials used a regional digital elevation model (DEM) of 100 nm by 100 nm with multi-resolution post-spacing varying between 1 (~30 m post-spacing) and 3 (~100 m post-spacing) arc-seconds (approximately DTED Level 1 and 2, respectively).

Database Depiction

Database rendering performance is highly dependent upon the characteristics used in the portrayal of the DEM. From a given DEM, NASA has primarily evaluated two different texturing methods: elevation-based color-coding with generic texturing of the DEM (i.e., "Elevation-based Generic") or ortho-rectified photographic imagery overlays on the DEM (i.e., "Photo-Realistic").

- To create the SV-HDD photo-realistic terrain database for the DFW and EGE flight trials, multi-resolution imagery (ranging from 1 to 32 meters/pixel) was obtained and overlaid on the DEM. A important aspect of the photo-realistic database development has been color-balancing of the various tiles in the photo imagery.

- To create the SV-HDD generic terrain database for the EGE flight trials, a color mapping technique (i.e., “elevation shading”), loosely based on Aeronautical Chart legends, was used. The colors ranged from greens, to browns, to light tans, to off-white for the lowest to highest elevation bands. 12 bands were used, segmented into 250 meter ranges. Real-time encoding of the DEM based on relative terrain altitude was not used. Similar generic texturing was also used at DFW.

No statistically-significant differences in the pilot's ability to fly the aircraft with the synthetic vision display concepts have been found between the generic and photo-realistic terrain depictions. In the EGE flight trials, subjective ratings of terrain awareness, given immediately after each data run, also showed essentially no differences between the generic and photo-realistic texturing.

However, a general subjective pilot preference for photo-realistic was been found in all flight trials, and in a usability study with General Aviation (GA) pilots. The photo-realistic terrain texturing provides a subjective improvement in awareness of terrain, better awareness of cultural features (towns, roads, etc), and subjectively better depth perception cues.

Several design characteristics have been found in the numerous studies which, taken collectively, provide design guidance and requirements:

- A key component of the NASA generically-textured DEM is cultural feature data. Pilot opinion strongly suggest that the demarcation of road and water, for instance, to the generic texturing greately enhances the situation awareness attributes of the SV terrain image. If cultural features were not an inherent feature, the quantitative "tie" between photo-realistic and generic-texturing may not necessarily be maintained.

- Although fish-net or grid patterns of terrain have been shown to add flow, perspective, and splay (which promote pilot perception of speed, aimpoint, and closure (Reference 10)), previous research also indicates that terrain texturing can provide these same elements while also promoting better situation awareness and user acceptance.

- The augmentation of a grid pattern into generic-textured and photo-realistic textured databases has been briefly evaluated under the Synthetic Vision - General Aviation element. The results were inconclusive. To date, the ability of the pilots' to judge speed, aimpoint, and closure has not been noted as a deficiency in any of the head-down display concepts, so the use of grid patterns has not been a necessity. However, as mentioned previously, the insertion of a grid pattern into generic-textured or photo-realistic textured databases in the SV-HUD implementations will be pursued for legibility considerations.

- One new concept being considered at the present time is elevation-coding of photographic imagery to create a blended elevation-based generic/photo-realistic database. With several high resolution monochromatic imagery sources available, the concept blends an elevation-based generic DEM with these high resolution monochromatic images to enhance elevation differences. This blended database would obviate the problems associated with color-balancing photographic imagery and "seasonal" effects that can detract from the quality of a photo-realistic database.

- In the vicinity of the airport, post-processing of the DEM is conducted (i.e., "bull-dozing" the airport property) to insert polygon models of the runway and airport. Without leveling the area, peculiar artifacts, such as portions of airport buildings and uneven runways, are prominently in the DEM. These artifacts can be quite unsightly and distracting (Figure 10). Also, the object models do not blur when in close proximity as phototexture often does.

- The complexity of the airport model has been dependent upon the flight test objectives. In the upcoming InSITE flight test, the airport model complexity and accuracy requirements will be elevated as Synthetic Vision display concepts are integrated with the Runway Incursion Prevention System (RIPS) technology (Reference 15-16) which relies on Enhanced Moving Map (EMM) technologies. Thus, a complex airport model will be required for surface operation evaluations.

BENEFITS

Several benefits analyses have been conducted within the SVS Project along several different directions - including operational and safety benefits.

Following the development of a concept of operations (Reference 17), operational benefits of synthetic vision were projected from two studies by Logistics Management Institute (Reference 18-19). While these studies are enlightening in the benefits analysis, two notable limitations to the study are: a) the cost of the systems are not available - hence, the vital cost-benefit relationship is not available; and, b) FAA certification and potential regulatory and airspace changes may be necessary to fully implement Synthetic Vision and reap the benefits. Certification issues from the SVS project perspective are addressed later in this paper.

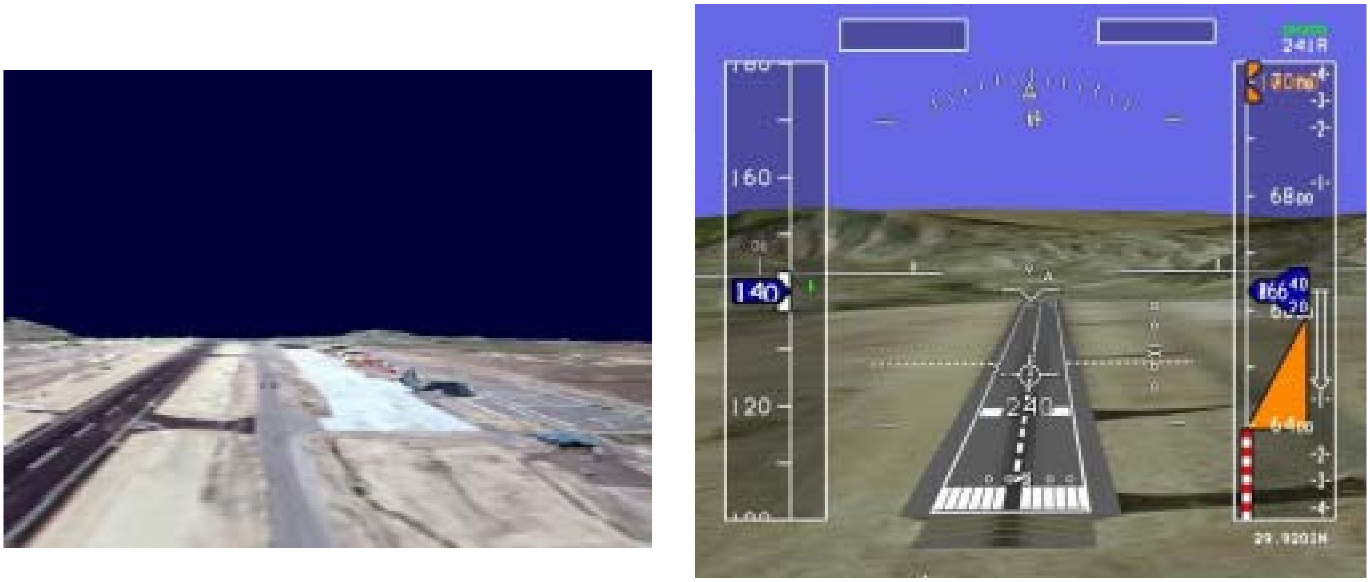


Figure 10: ORIGINAL IMAGERY COMPARED TO FINAL POLYGON RUNWAY AT EGE

CFIT Avoidance

The prevention or elimination of Controlled-Flight-Into-Terrain (CFIT) accidents is the obvious safety benefit targeted by SVS. CFIT benefit studies are in progress throughout the SV program but one component in these studies that may be difficult to overcome is the previous pilot experience.

As noted in previous studies of terrain display concepts for CFIT avoidance (Reference 20), the pilot participants did not have trust in the displays due to their novelty. CFIT avoidance benefit was consequently not demonstrated, particularly when the display contradicted their previous training or (simulated) Air Traffic Control directions. These data suggest that a training program will be necessary to demonstrate SVS accuracy and reliability in order to reap the benefits of SVS technologies.

ADVANCED GUIDANCE

The primary focus of the NASA Synthetic Vision project has been on the development of affordable, certifiable display configurations which provide intuitive out-the-window terrain and obstacle information. An adjunct to this endeavor is the addition of guidance information for navigation and obstacle avoidance. Consequently, tunnel or "highway-in-the-sky" depictions have been integrated into the synthetic vision display concepts based on their previous successes (e.g., Reference 21).

Tunnel and Path Guidance Depiction

A tunnel or pathway guidance concept has been nominally drawn on the NASA SV-HUD and SV-HDD concepts for approach guidance to increase the pilot’s situation awareness of the desired aircraft trajectory. The display objective is to create path awareness while not obscuring or occluding the terrain portrayal of the synthetic vision image. With this objective, a “minimalist” tunnel concept was constructed using “crow’s feet.” The crow’s feet were spaced at 0.2 nm along the desired path. The top crow’s feet of the tunnel were only displayed up to 1.0 nm in front of the aircraft. The bottom crow’s feet are linearly scaled in brightness, so by 3.0 nm from own-ship, the brightness of the bottom crow’s feet was reduced to zero.

Additional guidance information for the SV display concepts has been nominally provided by a ghost airplane symbol. The ghost airplane was positioned by a modified form of pursuit guidance, documented in Reference 22, to keep the aircraft trajectory tracking the tunnel.

While clutter is minimized with this minimalist tunnel concept, the typical tunnel benefits of the pathway awareness and the turn anticipation are somewhat lacking. Research into dynamic tunnel depiction concepts are in progress. The work will investigate display formats to minimize clutter when on path, yet enhance path awareness and path reacquisition as it becomes necessary.

Tunnel guidance for synthetic vision applications is also being compared to other more traditional guidance methods, such as dual or single cue flight directors. Particular research emphasis is being given to cognitive attention and task "acquisition" for displays with and without terrain or tunnels.

One area of concern with tunnel displays arises in their use during a missed approach or take-off task. The concern results from the depiction of a pre-defined path when the vertical flight performance of an aircraft should neither be constrained nor should it depict unachievable flight performance. An alternative is to dynamically vary the tunnel path based on predicted or actual performance, but these concepts carry with them concern over pilot misinterpretation and the potential for display of hazardously misleading information.

CERTIFICATION ISSUES

The benefits of advanced guidance and terrain depiction in SVS display concepts will be all for naught if these display concepts cannot be certified for operational use.

The primary hurdle to certification will be to overcome the "hazardously-misleading information" conundrum. The displays are being considered for certification as providing primary flight information; that is, a pilot will be controlling and navigating their aircraft with respect to the synthetic image, instead of just providing situation awareness. (The TAWS and Enhanced-Ground Proximity Warning System (E-GPWS) display information are for pilot situation awareness-only.). However, the FAA has never "certified" a database which appears to preclude a database-derived display as primary flight information.

Two SVS program initiatives are focused on these issues by developing potential techniques that might preclude SVS display of hazardously-misleading information.

Database Integrity

CRA work with Jeppesen is focused on methods to ensure process accuracy and integrity during the life cycle of synthetic vision databases. Complementary to this work, real-time accuracy and integrity work is on-going in the development of Database Integrity Monitoring Equipment (DIME). The general concept of DIME involves real-time comparison between actual sensor terrain measurements using, for example, downward looking radar altimetry or forward-looking Weather Radar Terrain Feature Extraction, and the stored database (Figure 11). The objective of these two thrusts is to provide sufficient accuracy, reliability, and integrity to achieve primary flight display certification status using database information.

Sensor-Enhanced SVS

The second effort also focuses on assurance in the accuracy of synthetic vision database information as well as augmenting the synthetic image with required real-time, non-database elements.

Historically, EVS and SVS have been perceived as competing technologies and paradigms; both attempting to provide a complete picture of the terrain, the airport, and fixed/moving objects within the scene. Neither technology completely and reliably provides the total picture. EVS technologies have been shown to provide sufficient information to allow landings and many ground operations during instrument meteorological conditions (Reference 23); however, due to their inherent limitations (e.g., less than optimal resolution, scenes based upon infrared/microwave contrasts versus visible spectrum, visual artifacts, mounting/measurement accuracies, and system integrity assurance), the FAA has restricted the operational use of this technology pending in-service data and future experience (Reference 24). Conversely, while SVS has ample resolution and can provide natural looking scenes, real-time sensor feedback is needed to assure that the computer-generated scene is properly registered and contains all of the pertinent objects.

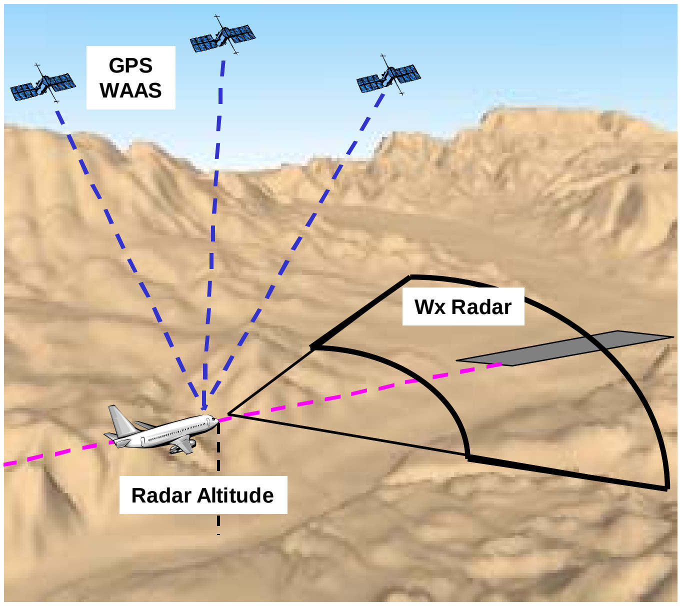


Figure 11: Database Integrity Monitoring Equipment

To provide SVS integrity, researchers at NASA Langley have developed a Sensor Enhanced-SVS (SE-SVS) concept which utilizes the beneficial (and complementary) aspects of EVS and SVS while mitigating the negative (or controversial) aspects of each paradigm (Reference 25-26). Rather than deploying more hardware, the NASA SE-SVS utilizes the weather radar, already on-board every commercial transport aircraft, to provide the integrity monitoring function. Previous systems have shown weather radar's capability to produce ground maps of the airport scene and surrounding terrain (Reference 27) and this ground map function will provide a forward-looking component to DIME.

A new radar technique (using a new generation of X-band weather radar) is also being investigated to improve both range and angular resolution to sufficiently detect and locate objects. Preliminary results show that this technique can provide 1-3 meter range resolution and less than 1 degree of angular resolution (1/3 of a degree being the goal). This additional capability allows for a wide variety of SE-SVS functions, which will be investigated in the InSITE flight trials, specifically:

- Air-to-air traffic surveillance
- Air-to-ground traffic surveillance (including runway incursion detection)
- Independent airport registration (including runway confirmation)
- Air-to-ground object detection (locating objects which impinge upon the airspace, and augmenting the database with those hazards not contained within the database).

These SE-SVS "products" complement the SV database display concepts to create the requisite real-time object detection and display integrity functions for a certifiable SV system.

CONCLUDING REMARKS

Within NASA's Aviation Safety Program, the Synthetic Vision Systems Project is developing display system concepts to improve pilot terrain/situation awareness by providing a perspective synthetic view of the outside world through an on-board database driven by precise aircraft positioning information updating via Global Positioning System-based data. This work is aimed at eliminating visibility-induced errors and low visibility conditions as a causal factor to civil aircraft accidents, as well as replicating the operational benefits of clear day flight operations regardless of the actual outside visibility condition. Numerous research and development activities have been conducted and more are in progress or planning to evaluate, investigate, and assess the technology which can lead to operational and certified SVS. From these works and through the cooperative efforts of industry and the FAA, certified SVS display concepts could be operational in the very near future, providing quantifiable operational and safety benefits.

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