U.S. Department of Transportation
Federal Aviation Administration

Advisory Circular

Subject: SYNTHETIC VISION AND PATHWAY DEPICTIONS ON THE PRIMARY FLIGHT DISPLAY

Date: DRAFT
Initiated By: ACE-100

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Change:

1. PURPOSE.

a. This Advisory Circular (AC) sets forth an acceptable means, but not the only means, of showing compliance with Title 14 Code of Federal Regulations (14 CFR) part 23 for two new concepts in small airplanes. The two concepts are: (1) Synthetic Vision (SV), and (2) pathway depictions displaying the navigation course on the primary flight display.

b. This AC covers airplanes in the normal, utility, acrobatic, and commuter categories approved to fly under Instrument Flight Rules (IFR).

c. Material in this AC is neither mandatory nor regulatory in nature and does not constitute a regulation.

2. BACKGROUND.

a. Description and Certification Experience. SV is a technology that has the potential to reduce fatal Instrument Meteorological Conditions (IMC), night, and low-visibility accidents. These three areas of operation represent the majority of fatal accidents in general aviation. A computer generated-SV image is a pictorial scene viewed from the pilot's perspective that is derived from: (1) aircraft state data (including heading, airspeed, and attitude), (2) a navigation position and direction, and (3) a database of terrain, obstacles, and relevant cultural features. Interest in this type of display is not new; it originated in the 1950's with the Joint Army-Navy Instrumentation Research (JANAIR) Program. Since then, many research programs have published findings supporting the benefits of both SV and display technologies. (See Appendix 1.)

(1) There are hundreds of variables that can distinguish one display system from another. Depending on the design implementation, an SV/pathway system might not provide a safety improvement. Because of the number of variables, a multiple pilot evaluation is required for all new displays incorporating SV and/or pathway symbology to ensure there are no unsafe features. While this technology is still new, previous part 23 research and certification experience provided lessons that are incorporated in this AC.

(2) The Federal Aviation Administration (FAA) approved a three-dimensional, synthetic image on the background of the pilot's Primary Flight Display (PFD). The synthetic image is a pilot's perspective view and is presented behind the standard PFD symbology. The system also included pathway guidance using a series of boxes to project a three-dimensional depiction of the pilot's selected course. The pathway provides Global Positioning System (GPS)/Wide Area Augmentation System (WAAS) approved non-precision approach guidance as well as enroute lateral and vertical guidance.

b. Advanced General Aviation Transport Experiment (AGATE), Research Experience, and Safer Skies Recommendations. In 1994, the AGATE (comprised of National Aeronautics and Space Administration (NASA), FAA, and private industry) envisioned flight displays that artificially made all flying resemble daytime, clear weather conditions. The members of the AGATE group believed that by making all instrument flying displays as easy as flying on a clear day those displays would minimize the mistakes made while flying in IMC. This belief was supported by the General Aviation (GA) accident history. The AGATE program solidified the FAA, NASA, and industry desire to make all flying as close to clear day conditions as possible, not only for increased GA utility but also for enhanced safety.

(1) Perspective displays, first proposed in the early 1950s as part of the JANAIR Program, required the maturation of electronic displays to come to fruition. The use of such SV displays enhances situation awareness and geographic awareness, although there is little objective data available. Most research results cite subjective pilot assessment of improved situation awareness. When combined with a pathway or tunnel display, improved tracking performance, with complex curved trajectories, has been reported. SV and pathway displays may improve performance and increase GA flight safety if there is an adequate demonstration of acceptable pilot workload and error detection, particularly in off-nominal conditions.

(2) NASA's goal in the AGATE program was to help the light airplane industry to recover the health that it enjoyed in the 1970's. Industry's goal in participating in AGATE was to get access to new technology that would help sell airplanes. The economic ramifications of this approach to GA flying are simple. To sell airplanes as useful transportation, they need to be nearly all-weather capable and offer safer operations than small airplanes offer today. The FAA's goal from AGATE participation was to get equipment that could also be retrofitted into the existing fleet, which would help reduce fatal accidents.

(3) NASA has been working with high resolution, SV displays since the high-speed civil transport project occurred in the late 1980's through the 1990's. They are flying SV displays in their B-757 (for part 25) and in their C-206 (for part 23). NASA SV GA studies published so far have used three-dimensional flight guidance; the guidance is three dimensional in the sense the more traditional two-dimensional flight director pitch and roll commands are augmented by time-based predictive components. NASA's three-dimensional presentations have shown reductions in pilot error and workload when compared to flying raw navigation data. The FAA's Civil Aero Medical Institute (CAMI) also has research using SV and pathway flight guidance. Their results also show that this technology has the potential to meet the AGATE safety expectations.

(4) In addition to the AGATE, NASA, and CAMI SV pathway research, "Safer Skies," which was the FAA and industry accident reduction effort, produced recommendations for part 23 Controlled Flight Into Terrain (CFIT) and weather accidents calling for reduced pilot workload. These reports, available on the FAA's Internet site (www.faa.gov), recommend the adoption of technologies like SV. The reports cite that new technology with the potential to reduce the pilot's mental workload during high task operations, such as approach, should reduce the number of fatal accidents.

3. APPLICABILITY.

a. This document is for airplane manufacturers, modifiers, part 23 airplane type certification engineers and their designees. The methods and procedures contained in this AC are available for use during all part 23 airplane certification activities.

b. This material is neither mandatory nor regulatory in nature and does not constitute a regulation. It describes acceptable means, but not the only means, for showing compliance with the applicable regulations. The FAA will consider other methods of demonstrating compliance that an applicant may elect to present. While these guidelines are not mandatory, they are derived from FAA and industry experience in determining compliance with the relevant regulations. If the FAA becomes aware of circumstances that convince us that following this AC would not result in compliance with the applicable regulations, we will not be bound by the terms of this AC. The FAA may require additional substantiation or design changes as a basis for findings of compliance.

c. This material does not change, create any additional, authorize change in, or allow deviations from regulatory requirements. Applicants should contact their Aircraft Certification Office (ACO) to determine the acceptability of any alternate means.

4. DEFINITIONS.

a. Synthetic Vision (SV). A computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft attitude (or state), high-precision navigation solution, and database of terrain, obstacles and relevant cultural features.

b. Synthetic Vision System (SVS). An electronic means to display a synthetic vision image of the external scene topography to the flight crew.

c. Pathway. A pathway display (often called a Highway In The Sky (HITS)) provides a picture of the selected or programmed navigation path to the pilot using a perspective view of a path through the airspace. The three-dimensional pathway provides navigation position information to the pilot.

d. Flight Path Marker (FPM)/Velocity Vector. The Flight Path Marker or velocity vector is a projection of the aircraft's path, that is, where the aircraft is going. This is sometimes called a velocity vector because that is what the symbol represents; however, since the symbol is typically an aircraft and not a vector, the symbol is more commonly called a flight path marker. If the flight path marker is designed to predict future position based on current aircraft state parameters, it may also be referred to as a flight path predictor.

e. Enhanced Flight Visibility (EFV). The average forward horizontal distance, from the cockpit of an aircraft in flight, at which prominent topographical objects may be clearly distinguished and identified by day or night by a pilot using an enhanced flight vision system.

f. Enhanced Flight Vision System (EFVS). 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, such as a forward looking infrared, millimeter wave radiometry, millimeter wave radar, and low light level image intensifying sensor.

g. Digital Elevation Model (DEM). Terrain database data used to draw the terrain image on a synthetic vision display.

h. Drawing Order. Drawing order is the sequential layering of symbology drawn on the PFD or other electronic display.

5. RELATED DOCUMENTS

a. SAE ARP 4102/7, "Electronic Displays," July 1, 1988.

b. MIL-STD-1787C, "Aircraft Display Symbology," January 5, 2001.

c. RTCA DO-200A, "Standards For Processing Aeronautical Data," September 28, 1998.

d. RTCA DO-276, "User Requirements For Terrain and Obstacle Data," March 5, 2002.

e. TSO-C151b, "Terrain Awareness And Warning System," December 17, 2002.

f. Theunissen, E., "Integrated Design Of A Man-Machine Interface For 4D Navigation," Delft: Delft University Press, 1997.

g. Mulder, M., "Cybernetics of Tunnel-in-the-Sky Displays," Delft: Delft University Press, 1999.

h. Beringer, DB, "Development of Highway-in-the-Sky Displays for Flightpath Guidance: History, Performance Results, Guidelines," Proceedings of the 43rd Annual Meeting of the Human Factors and Ergonomics Society, paper 3, 2000.

i. Newman, RL and Mulder, M (2003), "Pathway Displays: A Literature Review," Proceedings 22nd Digital Avionics Systems Conference, Indianapolis, October 2003, paper 9D6.

j. Wilckens, V (1973), "Improvements in Pilot/Aircraft-Integration by Advanced Contact Analog Displays," Proceedings of the 9th Annual Conference on Manual Control, pp. 175-192.

k. Anderson, MW and Newman, RL (1994), "HUD Flight Testing: Lessons Learned," presented at Southwest Section SETP Symposium, Stone Mountain, Georgia, May 1994.

l. Schnell T., Kwon J., Merchant S., Etherington, T., Vogl, T., "Improved Flight Technical Performance in Flight Decks Equipped with Synthetic Vision Information System Displays," International Journal of Aviation Psychology, 14(1), 2004.

m. Schnell, T., Lemos, K., Keller, M., Yang, S., Synthetic Vision Systems, "Optimum Display Characteristics," Final Report, NASA Langley Research Center, Aviation Safety Program, Hampton, VA, 2003.

n. Schnell, T., Lemos K., "Terrain Sampling Density and Texture Requirements for Synthetic Vision Systems", Final Report, Submitted to Rockwell Collins Advanced Technology Center, 400 Collins Rd. NE, Cedar Rapids, IA 52498, 2003.

6. CERTIFICATION

a. Specific Features. This AC provides guidance for specific SV system features considered necessary for the safe operation of a SV equipped part 23 airplanes. This AC separately addresses specific features considered necessary for pathway flight guidance. While the two technologies complement each other, they can be incorporated independently. The guidance in this AC is based on SV research and experience gained during the certification of existing SV systems. New systems may need additional features for safe operation, and policy/guidance for those features will be issued on an individual basis.

b. Heads-Up Displays. Providing complete guidance for SV systems is difficult because there are many design variables available to avionics manufacturers. Since SV displays have many characteristics in common with Head-Up Displays (HUD) when compared to traditional Head-Down Displays (HDD), applicants may use HUD display guidance where it makes sense. Specifically, symbols like the flight path marker may be based on HUD guidelines such as SAE ARP 4102/7; part 25 guidance on HUDs; and MIL-STD-1787C, the Department of Defense interface standard for aircraft display symbology.

c. Intended Function. Applicants need to clearly define the intended function of their synthetic depiction and pathway (as applicable). This will help the FAA develop appropriate evaluation criteria. For example:

(1) Will the terrain depiction be used only for terrain awareness or for terrain avoidance?

(2) Are the elements of the pathway display intended to be used with or as a substitute for a Course Deviation Indicator (CDI)?

(3) Is the pathway limited to non-precision approaches only or will it include precision approaches?

d. Appropriate Display. The applicant must show that the SV display is appropriate for this clearly stated intended function. For example, if the intended function is "terrain awareness," the applicant must show that the "awareness" is consistent with the actual terrain. That is, the display must not create an impression that the terrain is less of a threat than it actually is. This would constitute a misleading and inappropriate "terrain awareness" that would not be compliant with § 23.1301(a). The applicant should conduct a demonstration program to show that the display provides a reasonable representation of the terrain in a manner that does not misrepresent the threat posed by the terrain. The display, while possibly resolution or field-of-view limited, may still adequately portray the terrain for terrain awareness. This affect is similar to a "compressed" rear view mirror in a car. The mirror compresses the traffic picture so "objects in this mirror are closer than they appear." Though not "accurate," this approach effectively shows traffic in the car's blind spot.

7. SPECIFIC GUIDANCE FOR SYNTHETIC VISION.

a. Synthetic Terrain/Vision Imagery.

(1) The synthetic terrain/vision image is intended to enhance the pilot's terrain and/or situation awareness during flight in limited visibility, particularly during the critical phases of flight such as instrument approaches. The terrain image is based on the use of data from a DEM that is stored within the SV system. Additional features such as obstacles, runways, and landmarks should be integrated into the display complementing the terrain and helping the pilots correlate their position on an approach plate with the real world.

(2) Currently, the integration of synthetic terrain/vision as a background image on a PFD is a novel feature that may have the potential to not only degrade PFD readability and interpretability but also to provide misleading terrain and orientation cues. These potential safety issues must be assessed under both normal and abnormal conditions. In addition, the applicant's system must be shown to provide a level of safety at least equal to the conventional flight instruments it replaces. Therefore, applicants should consider providing a means to remove the SV display and revert to traditional blue over brown.

b. Terrain Awareness Warning System (TAWS). Any airplane equipment incorporating an SV system should also provide some type of terrain warning for the pilot. The terrain warning feature should be incorporated on the Multifunction Display (MFD) or separate display unless the applicant can demonstrate that their feature is effective on the Primary Flight Display (PFD). SV systems on the PFD so far do not provide adequate altitude and distance cues needed for terrain warning.

(1) Applicants may use TSO-C151b, Class A, B, or C standards; or applicants may develop their own terrain warning system. Applicants who want to develop their own terrain warning system should include:

(a) A one-minute caution and 30-second warning if the airplane's current flight path will collide with terrain or an obstacle.

(b) Aural call-out for both the caution and the warning (CAUTION – TERRAIN, TERRAIN; WARNING – TERRAIN, TERRAIN).

(c) Terrain impact region highlighted on the moving map.

(d) A safety margin or buffer of at least 100 feet for cumulative errors in both the GPS altitude and terrain database.

(e) A terrain database/DEM developed using the criteria in RTCA DO-200A, "Standards For Processing Aeronautical Data," September 28, 1998.

(f) The SV display must not provide any information that is in conflict with or incompatible with either the terrain warning or terrain awareness functions of the TAWS.

(2) SV may be so compelling that pilots may try to use it beyond the intended function (for example, navigating at low level through terrain at night or marginal Visual Flight Rules (VFR) conditions). Current SV systems do not offer the depth/distance cueing necessary to be used for this function. Another way of saying this is that error margins are still too large to use any SV system alone for terrain avoidance. These systems must be used with other flight and navigation information. Display size constraints may result in a "compressed" display that has the potential to cause misleading altitude and range estimation. In addition, cumulative errors from GPS, terrain databases, and barometric altimetry systems may contribute to misleading distance and height cues. Adequate mitigation should be provided to avoid the effects of such hazards. Such mitigation may be incorporated in the design or may include training requirements or procedures to use other navigation sources. However, it is unwise to depend solely on Aircraft Flight Manual (AFM) limitations.

c. Airplane Reference Relative to Terrain. If terrain is displayed on the same instrument/display as the primary attitude indicator, the pilot should clearly be able to distinguish between terrain above and below the airplane. In other words, terrain above the aircraft's altitude should appear above the horizon line, and conversely, terrain below the aircraft's altitude should appear below the horizon line. Displays using a flight-path-marker should be designed such that when the flight-path-marker appears above the terrain, the airplane will clear the terrain and vice-versa.

d. Heading Integrity.

(1) SV displays may be aligned to the airplane's magnetic heading when displaying terrain and all other features. If the SV display of terrain is driven by the same sensor as the primary heading, a failure of this heading will cause the SV display to also be in error. Given the compelling nature of SV displays, misleading heading failures may be difficult to detect. Conversely, the SV display may make some heading failures easier to detect (that is, lateral inputs that result in no heading response) depending on system sensor architecture. The system must provide a level of safety that is at least equal to the conventional flight instrumentation it replaces. This includes failure detection. The FAA and applicant should review and assess the appropriate hazard category level for heading in SV systems. The hazard assessment needs to consider the sensors driving the terrain and the primary navigation instruments.

(2) We strongly recommend that flight guidance [based on GPS, Very High Frequency Omnidirectional Range (VOR), Instrument Landing System (ILS), Flight Management System (FMS)] be displayed using a different heading/track source than the one used to draw the SV/terrain presentation. Using different heading sources for SV and flight guidance should provide mitigation from heading/track source failure. There is an opportunity, with dual sensors, for the pilot to "see" the discrepancy and identify a heading failure in one of the two systems faster than with a single heading source driving traditional navigation displays.

e. Horizon Line.

(1) The horizon line should be constructed so it has a high contrast against most possible backgrounds. This is not normally an issue with traditional Attitude Direction Indicators (ADIs) because the horizon on these indicators is the boundary between two different colored areas. Many ADIs include a contrasting line between the sky and ground. It is possible to use a single-color line in terrain-depicting displays where the sky and ground representations are of known uniform colors. However, displays expected to portray a realistically colored terrain representation or a color enhanced terrain depiction having multiple, generic hues may require a horizon line having an outline that will contrast against all the hues.

(2) Changes in the shape and edges of background terrain images may provide false cues of aircraft attitude to the pilot, just as the real world can do in VFR or IFR-on-top conditions. The pilot may mistakenly use the terrain image to interpret a level horizon line. For example, a sloping terrain on limited field-of-view display may lead the pilot to use the flight controls to change aircraft attitude based on a false sensation of attitude. Dynamically changing terrain background shapes and edges may also create the false sensation of changing attitude. Existing guidance recommends a solid, bold artificial horizon line extending across the entire display, representing the aircraft's attitude relative to the horizon. However, this line should not be so bold to hide important display features.

f. Moving Map Display that Corresponds to and Complements SV PFD Display.

(1) SV depictions on the PFD have the potential to provide the pilot with enhanced terrain and landmark awareness during non-precision and precision approaches. However, the display may not provide depth perception and may not provide a field-of-view for the pilot to know what is to the left and right of the display view area. When viewing the terrain on a limited field-of-view display, the pilot may mistakenly infer the location of the aircraft relative to the terrain.

(2) There should be a second, complementary plan view display. The second display should depict the same terrain, obstacles, and features that appear on the PFDs SV display. This display should be the navigation display, but it could also be an MFD or a third, separate display. Ideally, the TAWS system should be part of this display so that hazardous terrain or obstacles are highlighted.

g. Failure Modes.

(1) Failure modes of the terrain display should either be clearly annunciated to the pilot or addressed internally by the system. The failure should be identified before the pilot’s reaction to a misleading display could become hazardous. Examples are the terrain display failing in pitch and roll. The display should not cause the pilot to pitch or roll beyond safe limits before the failure is obvious or annunciated to the pilot. (Safe limits are considered +/-10 degrees of pitch and +/- 20 degrees of roll.) The pilot's reactions to these failure modes must be investigated during the FAA pilot evaluations.

(2) Failure of the Attitude and Heading Reference Systems (AHRS) or GPS source should be immediately annunciated and the applicant's Failure Mode and Effects Analysis (FMEA) should include every possible combination of failures that could affect terrain display and its interface with the pathway or other navigation data in use.

h. Terrain Color and Depiction. Terrain coloring and shading techniques that are effective in conveying terrain information to the pilot should be considered. These techniques must make the separation between sky and ground obvious. Currently, blue over brown is required on the attitude display; however, an equivalent safety finding may be possible on an individual basis for multiple colors. Constant color (brown) terrain has been used effectively and can be enhanced with texturing and shading.

(1) Experience has shown that large bodies of water should be displayed. This might be done effectively using a blue over dark blue or blue over black concept. Applicants might consider applying different techniques such as texturing to distinguish between ground/water and sky.

(2) Also, NASA research and research conducted at the University of Iowa showed that some particular terrain portrayal coloring techniques are more effective than constant color terrain displays. Applying color bands to depict the height of the terrain relative to the airplane may enhance elevation cues. Shading, texturing, and shadowing techniques have also proven effective in realistic terrain portrayal. For shadowing, the light source (sun angle) positioning must be carefully controlled to avoid obscuring important terrain features by shadows. One example of a researched texturing method is a lit and shaded checkerboard pattern of dark and light brown hues, with the checkers being oriented in the cardinal directions. Applicants should consider symbology contrast, sunlight readability, and brightness at night when using lighter colors for terrain.

(3) The traditional flight symbology, such as the pitch ladder, and the new symbology used on the SV displays (like towers and traffic) should always be viewable without being washed out against the terrain background. Applicants need to consider the layering priority of symbology. For example, the pitch ladder should appear on top of obstacles and terrain features.

i. Minimums Audio Callout Capability.

(1) Applicants should incorporate either a pilot selectable or automatic altitude alert with audio callout to remind pilots they are approaching minimums. Pilots may “see” the runway environment on their SV display and continue below minimums inadvertently because they were so intent on following the approach guidance. This scenario is similar to a pilot fixating on a flight director and descending below minimums. Alerting the pilot that they are nearing minimums reduces the opportunity for this situation to occur.

(2) This alerting feature can be easily implemented using existing barometric altitude alerting systems. These systems, including altitude bugs, have been included in most new GA Electronic Flight Instrumentation System (EFIS) systems. If a radio altimeter is installed in the aircraft, the minimums callout should be based on the radio altitude. However, where a radio altimeter is not installed, the minimums callout should be based on the barometric altitude setting.

j. Cultural Features. With a three-dimensional display, the pilot should be able to determine their relative position to important landmarks like the runway, terrain, and obstacles (such as towers). These features can easily be cross-referenced on a published approach chart. Since the FAA's goal is to reduce accidents (see Safer Skies recommendations, available at www.faa.gov), applicants should consider adding features that increase the pilot’s situation awareness and reduce the pilot's mental workload.

(1) Once an applicant decides to incorporate three-dimensional terrain, they should consider displaying all the features and information necessary to reproduce a clear, daytime picture that also correlates directly to approach charts. The database incorporating these features should not conflict with other navigation information. Also, update cycles and information currency should be considered.

(2) Display of lakes, rivers, roads, train tracks, and so on, may be considered on the PFD. While these features are common on MFDs/moving maps, they might prove of limited use on a PFD. The risk is that the display could become too cluttered and it would need to be evaluated by the FAA.

(a) Obstacles. Besides including synthetically drawn terrain on the PFD, applicants should consider including all charted obstacles (existing government databases include all obstacles greater than 200 feet in height). Once an applicant commits to presenting a three-dimensional depiction of the terrain on the PFD, pilots may be compelled to trust the display in low visibility conditions such as haze. In many areas like the Midwestern US, terrain will look like a flat background. The terrain depiction increases the pilot's comfort level that their flight altitude is safe; however, towers and tall buildings can present a significant safety threat. Pilots using an SV PFD may be enticed to rely on the terrain information, forgetting about tall obstacles such as towers. SV displays should include all hazards (readily available in databases) that a pilot could hit, not just terrain.

NOTE 1: The limitations of the on-board database supporting the SV display should be clearly identified and there should be analysis of the potential for Hazardously Misleading Information (HMI) resulting from pilots misinterpreting the SV display because of these limitations. For example, if the database is comprised solely of Digital Terrain Elevation Data (DTED) and no other features (such as towers, buildings, and vegetation), then the fidelity of the data should be identified. Any operational limitations that result from this analysis should be reflected in the pilot’s procedures for operating the system and found in the Aircraft Flight Manual (AFM) supplement and the pilot's operating manual.

(b) Runways. Displaying airport runways is a desirable feature, especially while conducting an instrument or visual approach. The runway anchors the approach. Also, TAWS alerting envelopes are a function of distance from the airport (per TSO C151), and all predictive TAWS alerts must be inhibited at some time on final approach to avoid nuisance alerts. Therefore, many TAWS AFM supplements have requirements that the TAWS be inhibited when flying into airports that are not in the TAWS airport database. For most systems, it is not readily obvious whether the destination airport is in the database. As TAWS equipment is installed in smaller aircraft flying into more remote locations with shorter runways, the problems associated with airports not in the TAWS database will only increase. Portraying airport runways on the PFD and/or MFD would minimize this problem. Runways should be depicted on both the PFD and the MFD; however, beyond a certain range on the MFD, it is preferable to depict the airport instead of the runways.

k. DEM Resolution. The DEM resolution is one factor that determines how well the SV terrain depiction will match the terrain environment. NASA experiments have shown that a terrain resolution of 30-arc-seconds “rounds off” the vertical features of the terrain. This makes the terrain appear less hazardous than it is and potentially reduces some safety benefit. The same set of NASA experiments pointed out that even though pilots preferred terrain created using higher resolutions (one and three-arc-seconds), an SV display using a 30-arc-second database could provide more situation awareness (and, therefore, safety) than the conventional round dial instrument panel. For these reasons, 30-arc-second resolution should be considered the minimum safety standard for SV displays. Depending on the intended function of the terrain, applicants should strive to match the DEM resolution used in Technical Standard Orders (TSOs) for TAWS with areas of varying terrain and near airports. More importantly, applicants should define the resolution of the DEM used by their SV system in the Aircraft Flight Manual

Supplement (AFMS) and the pilot's handbook by using units understood by pilots, such as feet instead of arc-second.

(1) The guidance in this AC is based on the terrain display being approved for awareness and not for navigation or terrain avoidance. If an applicant wants more credit for their terrain and has the terrain database integrity to support it, the DEM resolution will need to be higher than is acceptable for awareness only.

NOTE 2: TSO-C151B, Appendix 1, paragraph 6.3, recommends a resolution of 15-arc seconds for TAWS. Also, RTCA DO-276 specifies a resolution of three-arc-seconds in the enroute environment and one-arc-second in terminal areas. While these resolutions are not required for SV systems, they are recommended targets for resolution.

NOTE 3: The DEM resolution needed on an SV display depends on the intended function of that display. Applicants need to consider how they are going to use the terrain database information for their SV display, and this information should be given to the FAA at the beginning of an SV certification program. As used in RTCA DO-276, several metadata elements are required, including post-spacing (that is, resolution). One element, the elevation reference, is closely related to DEM resolution. The elevation reference indicates how elevation values are assigned for the cells in the DEM. A single-elevation value in a 15-arc-second DEM represents an area approximately 0.25 x 0.25 nautical mile. Common elevation references are average elevation, maximum elevation, and sometimes, the elevation of the geometric center of the area. As post-spacing increases, the difference between the DEM value and the actual elevation of a point within a cell may differ by several hundred meters. The elevations used for an SV display should be conservative; use the highest elevation for a given cell. This concept is identical to the current sectional charts labeling the highest elevation in the given quadrangle (square sector) of latitude and longitude.

(2) Applicants should establish acceptable means for insuring the currency of the database.

l. Terrain Database Integrity. Besides resolution, a high integrity terrain database is critical to safe implementation of SV. The database should meet the highest levels of integrity as specified in DO-200A and DO-276. Applicants should provide the FAA with thorough explanations on how they develop and maintain their database integrity.

m. Display Update Rates.

(1) The primary features of the PFD need to update fast enough to provide a smooth depiction of motion for all reasonable flight maneuvers appropriate for the class of airplane. The loss of terrain update (for example "frozen screen," and failure to update) should be shown to be extremely improbable. Besides failure annunciation, the terrain display should be removed when errors are detected.

(2) Update rates vary for different sources of information. This variation may be acceptable, depending on the intended function and the implementation of the SV display. For example, the update rate on an SV function integrated with the ADI may need to be substantially higher than an SV function integrated with a lateral nav display. The applicant should show by simulation or flight test that the display update rate is appropriate. For integration into primary flight or navigation displays, the SV display should be updated at a rate equivalent to that of the rest of the display. This will prevent disagreement between the primary display functions and the SV background.

n. Aircraft Flight Manual Supplement (AFMS). The AFMS should contain limitations for the pilot on use of the applicant's system. These limitations should be explained in detail. Warnings, cautions, and notes should also address the proper use and potential misuse of the display for terrain awareness and avoidance. Finally, the applicant should provide information describing how well the synthetic terrain represents the actual terrain.

> **NOTE 4:** An acceptable description of the terrain data should include the data elements given in RTCA DO-276 (Section 3, Table 3-1). In addition, DO-276 provides other requirements for terrain data content and quality that could be included in the description if applicable.

o. Unusual Attitude Recovery. Historically, the FAA has required all but essential flight information to be removed from the PFD in unusual attitudes. This "decluttering" was done to aid the pilot in recovering the airplane. Thus, the FAA approached the first SV systems similarly by asking applicants to remove the synthetic depiction and revert to the traditional "blue-over-brown" display during unusual attitudes.

(1) Recently, the FAA's center for physiological research, CAMI, conducted experiments to determine the effect the synthetic depiction had on unusual attitude recovery. One recommendation from that research was that the synthetic depiction remains on the PFD for unusual attitude recovery. There was little performance difference between recoveries with and without the synthetic depiction. There is a possibility that the pilot may be temporarily confused by the significant change to their primary attitude display. It is better to avoid the possibility of confusion and leave the synthetic depiction on the PFD.

(2) Some indication of both sky and ground should always be visible on the PFD for use in initiating unusual attitude recovery. Pilots should be able to initiate a recovery toward the correct horizon and altitude within one second of recognition (reference MIL-STD-1787C, Appendix E, Figure 91).

8. SPECIFIC GUIDANCE FOR PATHWAY DISPLAYS.

a. Pathway. Pathway depictions researched have typically, but not always, resulted in better pilot performance or lower pilot workload, or both. Research and experience highlighted the following recommendations:

(1) The pathway display should be damped enough so it is easy to fly. An undamped pathway may cause a pilot-induced-oscillation.

(2) The pathway should be designed to prevent excessive pathway chasing by the pilot.

(3) The pathway should also be easy to reacquire when it is not visible on the PFD. FAA certification pilots must evaluate the pathway implementation just as with the SV depiction.

(4) Applicants should be aware that a poorly implemented pathway can increase pilot workload and would not be approvable. The following are examples of issues that applicants should consider because, if implemented poorly, they could be misleading to less experienced pilots. These examples of important characteristics include:

(a) The default glide path depicted by the display should reflect the conditions that exist between any Missed Approach Point (MAP) waypoint and the runway (or should not be presented, except by pilot selection). This may require various angles to clear obstacles, not always 3.0 degrees; and,

(b) During the final approach segment, the pathway may follow a navigation database with coded vertical navigation path data on lateral navigation-only procedures. This provides the pilot with a presentation that descends along this lateral navigation path. Some approaches may require that the pilot maintain altitudes for step-down fixes or the Minimum Descent Altitude (MDA) up to the missed approach. The pathway should not go below altitude minimums during the step-down portion of the approach.

(c) Depending on the system architecture, the pathway may also drag the MAP waypoint down with it, giving the impression that a descent is required. The pathway should not cause the pilot to descend below minimum altitude.

(5) The intended function of the pathway needs to be clearly stated as addressed in section 5. The applicant and FAA need to be clear on which navigation sensor the pathway will use and how the pilot is expected to use the pathway. As a minimum, the applicant should consider the following:

(a) Is the pathway flight guidance or raw data?

(b) Can the pathway have multiple navigation sources?

(c) If so, how does the pilot know which navigation source is driving the pathway?

(d) If the pathway is GPS driven, how will it be used for "ground-based" precision approaches?

(e) How will vertical minimums be addressed?

(6) For enroute operations, the pathway must use barometric altitude for the vertical guidance because that is what is used in the airspace system. Barometric altitude is also used on approach unless the system uses navigation-system-derived vertical path guidance (ILS or GPS-based vertical navigation). Applicants should also consider providing the pilot with the option of dimming or removing the pathway and reverting to traditional flight guidance if available.

b. Pathway Lateral and Vertical Limits. Applicants should show that the pathway boundary is appropriate for the stated intended function. If intended as a secondary source of navigation information, the boundary markings must be consistent/compatible with the primary navigation sources (deviation indicators or flight directors). Research indicates that pilot training and experience strongly affect the usability of pathway boundaries. Applicants should develop a test program to show that their pathway boundaries allow for an acceptable level of usability performance by both inexperienced and experienced pilots. Vertical limits for non-precision and precision approaches are fixed at an MDA and Decision Altitude (DA). Pilots are still expected to comply with these limits by using the primary barometric altimeter. The AFM pathway description should clearly define the lateral and vertical limits of the pathway and how they are intended to be used.

c. Precision Approach Guidance. If an applicant chooses to provide precision approach guidance using a pathway depiction on an SV PFD, they should meet the applicable TSO performance requirements for the intended approaches.

(1) Applicants should consider using independent sensors to create the display symbology when two sensors are available. One example of dual sensor implementation is to use GPS for the pathway and ILS raw data for the precision approach guidance.

(2) Applicants using the same navigation positioning sensor for different approach guidance displays (for example, the same sensor driving the ILS flight director and the Pathway) should demonstrate the clear and unambiguous annunciation of failures in the pilot's primary field of view. Combined sensor approach guidance that includes a pathway may be more compelling than a single source of guidance. This situation increases the critical nature of the failure annunciation.

d. Pathways and Terrain. Hazardously misleading information could be displayed resulting from a misapplication of drawing order priorities. For example, the pathway may pass behind or through terrain. The terrain will not occlude the pathway if the pathway is drawn last (as is typically the practice). Pathway depictions on an SV PFD should address drawing order issues. The pathway is a compelling flight display and should never continue through terrain. If the programmed flight plan or immediate flight path has a terrain conflict, the system should alert the pilot. Terrain conflicts should be obvious to the pilot by the discontinuity of the pathway in or around terrain.

(1) Most research so far has been conducted during the approach phase of flight. Applicants should consider issues associated with other phases of flight such as climb, enroute, descent, and missed approach. In particular, non-ground referenced climb trajectories may indicate misleading vertical information. Applicants should include departure and enroute Air Traffic Control (ATC) scenarios for pathway operations.

(2) Applicants should also consider decluttering (removing) the pathway for unusual attitude recovery. Unusual attitude recovery will need to be examined during the pilot evaluation.

9. TEST AND EVALUATION METHODS AND CRITERIA FOR COMPLIANCE.

a. Pilot Evaluation. A pilot evaluation will be necessary for any SV display system. Often, it is useful to gather subjective pilot assessments of the SV displays. Questionnaires used with flight evaluations and/or simulation are good tools to use for pilot assessment, but they need to be specific rather than merely solicit general impressions. Accepted and proven evaluation protocol, measures, and scales should be used where applicable to ensure the integrity of the evaluation process. The questions should target specific information presented on the display, its intended function, and whether it is usable for flight tasks required for typical instrument and commercial ratings. Besides FAA pilots (including Designated Engineering Representative (DER) pilots), the applicant should consider conducting assessments with representative end user/operational pilots. Applicants should coordinate plans for any pilot evaluation with the Small Airplane Directorate and their responsible ACO.

b. Criticality. The following issues in (c) and (d) should be considered because of the critical nature of the attitude display, per §§ 23.1321(d)(1), and the critical phases of flight where the SV system will be used.

c. Evaluation Criteria. The integration of synthetic terrain/vision and/or pathway imagery on the background of a PFD will contain many features for which the FAA does not have standards or guidance. Therefore, besides the guidance in this AC, the display must be evaluated to ensure the following:

(1) The primary flight display meets its intended function; and,

(2) The additional and/or novel features of the synthetic terrain/vision and/or pathway imagery on the background of a PFD do not unacceptably compromise the functions and usability of the PFD. For example, the integration of a terrain image cannot result in hazardously misleading information with tasks flown using the attitude indicator.

d. Compelling Nature of the Display. A display intended to provide terrain/situation awareness information may draw attention away from other cockpit information and tasks. As a result, it may decrease pilot attention to other required duties. It is important that evaluation pilots assess the proposed displays in the overall context of the cockpit and in realistic scenarios. Evaluation pilots must specifically assess whether the proposed display alters the pilot's attention in an unsafe manner. Systems that include pathway flight guidance should be evaluated with the pathway on and off.

DRAFT

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APPENDIX 1 -BACKGROUND FOR SYNTHETIC VISION AND PATHWAY DISPLAYS-RESEARCH OVERVIEW PROVIDED BY NASA *(REPRINTED)*

The two display concepts applied to the Primary Flight Display (PFD) that are the subject of this Advisory Circular, Synthetic Vision (SV) and Pathway or Highway in the Sky Displays, have both been under investigation within the flight display research community for more than three decades. Prior to the more recent research in SV, these investigations usually have addressed the technologies separately. With the advent of more contemporary SV concepts, SV and Pathway or Highway in the Sky displays have become more closely coupled, as will be discussed.

The earliest flight display work in both technologies was limited graphically to connected straight line segments by the rendering capabilities available then as the state of the art (i.e., stroke generators). Because Pathway Displays attempted to represent the intended flight path of the airplane connecting geospatial waypoints, and because of the two dimensional nature of Instrument Landing Systems (ILS), which generated rectangular boundaries, the earliest Pathway Displays were quite amenable to stroke presentations. The natural inclination to include a runway representation at the end of the final approach segment of the Pathway Display led to its initial coupling with Synthetic Vision. In addition to a runway representation, some primitive attempts were also made to represent first, the ground plane, and eventually terrain. As computer graphics technology has matured, pathway (and terrain) presentations have improved dramatically, although the basic concept of presenting the desired vertical and lateral path ahead of the airplane, viewed from the pilot's position, in a three dimensional perspective scene has clearly been maintained. Within the flight display research community, while terminology may vary between Pathway, Highway, or even Tunnel Displays, and some concepts may employ different flight guidance strategies (including the total lack of flight-director-like guidance) and different pathway elements, common confusion over the definition of this type of flight display has never arisen.

However, even within the flight display research community, the term Synthetic Vision has had different interpretations through the years, which can still lead to some confusion. However, the community viewpoint has finally converged to an acceptance of the interpretation of Synthetic Vision as a pictorial scene viewed from the pilot's perspective which is rendered by a graphics computer based on a geospatial database of terrain, obstacles, and perhaps cultural features. Rudimentary Synthetic Vision Displays of the airport environment contained only a perspective runway outline and a horizon line, augmented perhaps with alphanumeric flight information when character generators became available (the terminology for these displays at that time was contact analog, rather than Synthetic Vision, displays). However, with the advent of raster graphics engines, filled polygons allowed for the presentation of more realistic, although somewhat cartoonish, airport scenes (which were commonly termed pictorial displays) and surrounding terrain.

Somewhat concurrent with the initial use of raster graphics in flight display research was a low visibility landing program conducted by the FAA which was titled the Synthetic Vision Flight Demonstration Program. Actually, using today's terminology, the program investigated Enhanced Vision Systems (EVS), which attempt to improve visual acquisition by enhancing significant components of the real world scene outside the aircraft. Enhanced vision systems typically use imaging sensors to penetrate weather phenomena such as darkness, fog, haze, rain, and/or snow, and the resulting enhanced scene, a sensor image, is presented on a Head-Up Display (HUD), through which the outside real world may also be visible.

Synthetic Vision acquired its present definition somewhat concurrent with the emergence of texturing capabilities, which allowed raster graphics engines to render more highly realistic scenes (in some concepts, aerial and/or satellite photography are used to provide photo-realistic scenes). Synthetic Vision Displays today are characterized by their ability to represent, in an intuitive manner, the visual information and cues that a flight crew would have in daylight -- Visual Meteorological Conditions (VMC). The view of the outside world is provided by melding computer generated airport scenes from on-board databases and flight display symbologies, in some cases with either information derived from a weather penetrating sensor (e.g., information from runway edge detection or object detection algorithms) or with actual imagery from such a sensor. The visual information and cues are depicted based on precise positioning information relative to the onboard terrain database, and may include traffic information from surveillance sources (such as Traffic Alert and Collision Avoidance System (TCAS), Airport Surface Detection Equipment (ASDE), etc.) and other hazard information (such as wind shear).

A bibliography was created to provide insight into the technical foundation of this Advisory Circular regarding Synthetic Vision and Pathway in the Sky Displays. While quite extensive, it is not intended to be exhaustive. In terms of the more recent papers, the bibliography is perhaps weighted heavily with those papers generated by either NASA researchers working within, or industry and university researchers sponsored by NASA programs in Large Screen Pictorial Displays, High Speed Research External Visibility Systems, and Synthetic Vision. The entire bibliography is intended to offer some of the more influential sources of highly relevant research-based information regarding the development and certification of Synthetic Vision and Pathway in the Sky Displays. NOTE: this bibliography is extensive, about 27 pages, and is therefore available online at the following address:

For a Word Document:

http://www.faa.gov/certification/aircraft/aceNASABibliography.doc

For a PDF Document

http://www.faa.gov/certification/aircraft/aceNASABibliography.pdf