MP 06W0000161

MITRE PRODUCT

Concept of Operations for the Use of Synthetic Vision System (SVS) Display During Precision Instrument Approach

August 2006

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Abstract

This paper describes a concept of operations for the use of Synthetic Vision System (SVS) display technology with Category (CAT) I, straight in instrument landing system (ILS) approach. A concept is proposed which extends the current authorization available under Code of Federal Regulations (CFR) Part 91.175 of the Federal Air Regulations (FAR) to begin descent from the published Decision Altitude (DA), based on visual sighting of approach lights. It is proposed that an extended runway centerline feature displayed on an SVS could be substituted for visual contact with the approach lights, as authorized in 91.175,[1] as long as this information is cross checked with the ILS signal. It requires the use of ILS signals for navigation down to 100 ft height above altitude (HAT), which is available for many ILS installations. Descent below 100 ft HAT would not be allowed unless other visual cues associated with the runway environment are clearly visible and identifiable by the pilot.

Issues and areas for future research to support this concept of operations are presented.

KEYWORDS: Synthetic Vision System, low visibility approach, Category I ILS, Category II ILS, weather minima, CFR Part 91.175.

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[1] This concept of operation uses provisions of CFR Part 91.175(c) and has no relationship to the authorizations extended for Enhanced Flight Vision Systems (EFVS) under Sections 91.175(l) and 91.175(m).

Acknowledgments

The author wishes to acknowledge the contributions of many people who were instrumental in the preparation of this paper. Our colleagues at the National Aeronautics and Space Administration (NASA) Langley Research Center; Steve Young, Randy Bailey, Lou Glaab, Lynda Kramer, and Michael Lightfoot have been extremely generous with their time and expertise in providing us with a broad base of prior research upon which we were able to build this concept of operations. My MITRE teammates, Bart Gallet, Brennan Haltli, Scott Williams, Capt. Al Herndon, Elly Smith; and especially Suzanne Porter, Project Team Manager, and Anand Mundra, our technical and organizational mentor who helped us navigate the thicket of organizations and regulations to get us where we needed to go; Vince Massimini for helping us understand global positioning system (GPS) navigation issues. At the Federal Aviation Administration (FAA), Les Smith, Terry Stubblefield, Dick Temple, and Ernie Skiver have been able to help us connect the research and science with the practical problems of actual certification. Finally, “thank you” to Cathy Champigny, who has done the heavy lifting of preparing the paper for an on-time delivery and publication.

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Section 1

Introduction

In the current operating environment, low visibility approach and landing operations require a combination of aircraft avionics equipage, surface infrastructure, and specific crew training to operate at reduced visibility. These requirements limit low visibility approaches to a relatively small number of runways. In order to improve operational performance and lower the cost of operations, it would be desirable to increase the availability of low visibility operations at a larger number of runways, and increase the reliability of operations at runways where low visibility operations are already being conducted.

The MITRE Corporation's Center for Advanced Aviation System Development (CAASD) was tasked during 2005 by the National Institute of Aerospace (NIA) to study applications of Enhanced Flight Vision Systems (EFVS) and Synthetic Vision Systems (SVS) technology being developed by the National Aeronautics and Space Administration (NASA) to enable low visibility operations where currently not possible due to limited surface infrastructure. This paper documents a concept for application of SVS to improve access to runways with straight-in Instrument Landing System (ILS) Category I approach capability. The concept is intended to guide further discussion, identify detailed requirements, conduct preliminary safety analyses, and identify issues that will require additional research or analysis. The paper also identifies key issues that must be addressed for extensions to other Global Positioning System (GPS) based precision and non-precision approaches.

The Federal Aviation Administration's (FAA) Advisory Circular (AC) 23-26, "Synthetic Vision and Pathway Depictions on the Primary Flight Display," defines synthetic vision as a computer-generated image of the external scene topography from the perspective of the flight deck that is derived from aircraft 3-D position, high-precision navigation solution, and database of terrain, obstacles and relevant cultural features. (FAA, 2005) Figure 1-1 illustrates one SVS display design with several key display features identified.

SVS provides useful imagery to the crew, from a cockpit-centered (egocentric) point of view, so that the terrain and cultural features (runways and associated features, obstacles, roadways, buildings) in its associated databases are rendered as a perspective real world image on a flight deck display. This image may include runways and associated features to support the runway visual acquisition and alignment task that must be completed for all instrument approaches, except those conducted under Category III (CAT III) weather conditions.

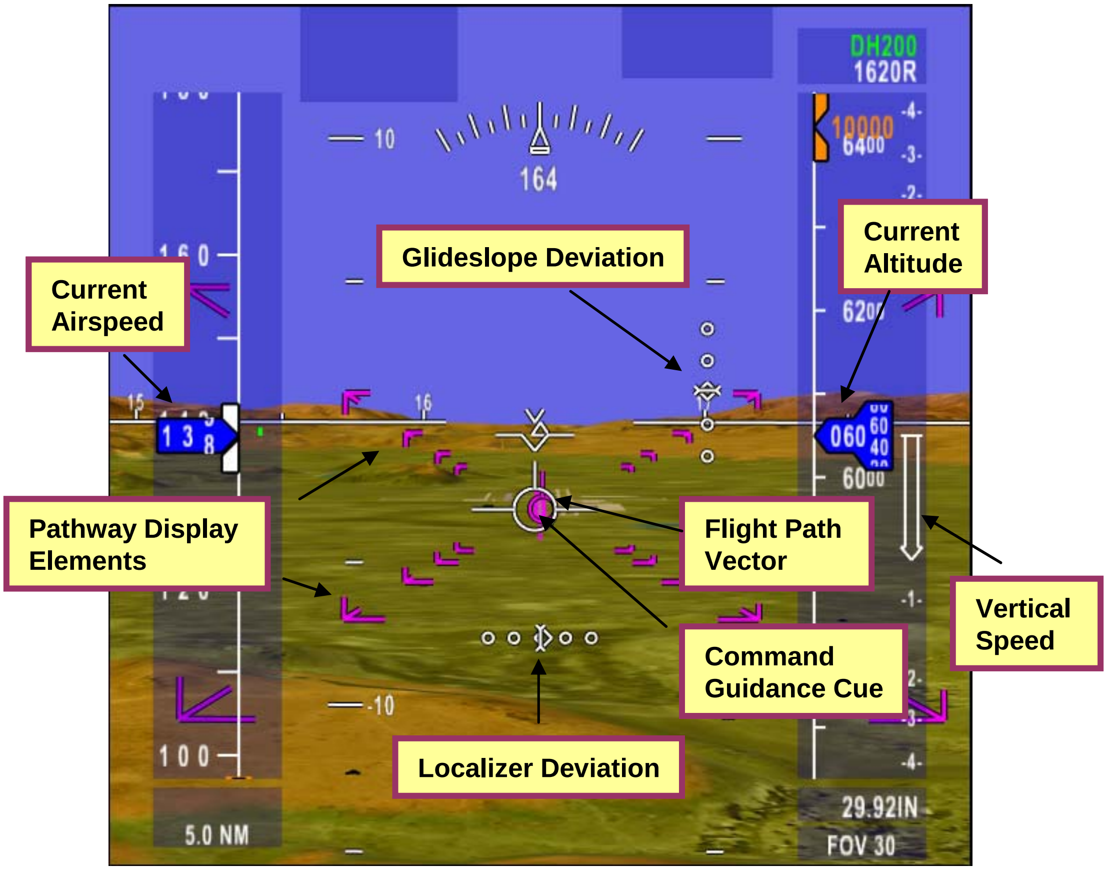

Figure 1-1. Example of Synthetic Vision System Display with Pathway Guidance (Courtesy of NASA Langley Research Center)

In addition, it must be recognized that SVSs are under active development and capabilities such as pathway guidance or flight path vector that may provide powerful cues in support of these critical pilot tasks of runway visual acquisition and alignment.

The integration of accurate and reliable high precision position information with robust database technology will enable the functional development of operational capabilities based on the visual scenes and cues generated by SVSs. These will provide pilots with an integrated, dynamic view of the runway environment that may be functionally equivalent to seeing the approaching runway and associated features through the windscreen. This will be an initial step in realizing the joint government/industry goal of Equivalent Visual Operations formulated by Next Generation Air Transportation System (NGATS) (Joint Planning and Development Office, 2006).

In January 2006, the FAA's Flight Standards office, in collaboration with NASA's Langley Research Center, embarked on an analysis of the feasibility of conducting CAT I straight in approaches with vertical guidance to a height above touchdown (HAT) of 100 ft with the help of an SVS. In addition, NASA also established a goal of studying the feasibility of extending the concept to other types of approaches, including non-precision approaches. The motivation, of course, is to provide low visibility access to as many runways and airports as possible, with the full equivalent level of safety available in current low visibility approaches. As a result of the discussions conducted with the FAA stake-holders, it became clear that this goal could not be achieved in a single step; that a useful intermediate step would be the conduct of CAT I ILS approaches down to 100 ft with SVS. This paper describes this first step. This approach provides an opportunity to develop operational experience with the new SVS capability in the context of ILS operations that have been used safely for many years. This will also provide room for maturing the technology to address the operational issues that will affect the potential extension to other GPS-based approaches. Whether application to non-precision approaches can be achieved must await further study.

Section 2

Background

This concept of operations proposes authorizing operations below published Category I ILS decision altitudes (DA) based on an integration of ILS and SVS. The following regulations and ILS performance requirements provide a regulatory and performance basis for considering this combination of technologies. The concept builds on authorizations already present in the governing regulations for CAT I ILS approaches, and the flight checked accuracy of the ILS navigation signal.

2.1 Current Operational Approval for ILS Operations Below Published Decision Altitude: Code of Federal Regulations (CFR), Part 91.175

Part 91.175 governs instrument approach and departure operations at civil airports in the United States. Its provisions apply to both precision and non-precision approaches. The regulation contains language governing when a pilot may leave the DA height (H), specifically defining the visual references that must be in view before an approach can continue below DA. A precondition for using any of the specified visual cues, is that the airplane is continuously in a position from which descent to landing can be made using normal maneuvers and a normal rate of descent. The flight visibility must also be not less than that prescribed for the approach being used. The rule includes an additional requirement that pilots operating under Part 121 (Air Carrier) and Part 135 (Commercial Operators) must be able to land in the touchdown zone of the runway.

Federal Aviation Regulation (FAR) 91.175 (c)(3) defines the visual references that can be used to initiate descent. At least one of the following ten visual references for the intended runway must be distinctly visible and identifiable to the pilot before leaving the published DA.[2] (Part 91.175 is provided in its entirety in Appendix A.)

(i) The approach light system, except that the pilot may not descend below 100 ft above the touchdown zone elevation using the approach lights as a reference unless the red terminating bars or the red side row bars are also distinctly visible and identifiable.

(ii) The threshold.

(iii) The threshold markings.

[2] Note that paragraphs 91.175 (l) and (m) were added to CFR Part 91.175 to authorize the use of EFVS. Nothing in this conops utilizes these latter authorizations.

(iv) The threshold lights.

(v) The runway end identifier lights.

(vi) The visual approach slope indicator.

(vii) The touchdown zone or touchdown zone markings.

(viii) The touchdown zone lights.

(ix) The runway or runway markings.

(x) The runway lights.

Note that paragraph (i) authorizes descent below the CAT I DA (but not below 100 ft HAT), based solely on *visual sighting* of the approach light system at the published DA. While the approach lights may provide lateral deviation information, pilots would not be expected to control the vertical path based on this reference alone. For this reason, the additional features required for continued descent below 100 ft HAT are specified in 91.175(c)(3), as quoted above. Operationally, it will be necessary that crews continue to track the localizer and glideslope to 100 ft HAT unless a specific limitation on such use below DA is depicted on the approach chart, in which case the proposed concept of operations would not be authorized.

Neither the regulation itself, nor AC 120-29 (FAA, 2002), which provides guidance on compliance with 91.175, specifies how 100 ft HAT altitude is determined under the authorization in 91.175. Since radar altimeter equipment is not a requirement, nor is it specified in this case for Category I ILS operations, it is presumably acceptable to use the barometric altimeter to determine the altitude that would be the equivalent to 100 ft HAT.[3]

In consideration of the foregoing, it appears that unaided visual detection of the approach light system is judged to be sufficient validation of the lateral position of the aircraft at 200 HAT, that descent along the ILS localizer and glideslope will result in a landing in the touchdown zone, and that further descent to 100 ft HAT can be safely performed. This permits additional time for the pilot to visually acquire the additional cues required to descend below 100 HAT as specified in 91.175(c)(3), determine that the flight visibility meets the requirements specified for the approach as required under 91.175(d)(2), and complete flare and landing.

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[3] It should be noted that paragraphs 91.175(l) and (m), which authorize the use of EFVS below DA, also do not require the use of a radar altimeter.

CAT I ILS operations have been conducted under the “continuation” authorization granted under 91.175(C)(3)(i) since the re-codification of Part 91 in August, 1990. Identical language is contained in Part 121.651 governing Air Carrier operations. Interestingly, the corresponding section of Part 135, specifically 135.225, “Takeoff and Landing Under IFR,” does *not* include the same language. It specifies more general requirements, that the operation be conducted using a standard instrument approach, and that the reported weather is above the minimum required at the time that the approach is started. There is no specific language governing descent below DA for Part 135 operations, except for the reference in 91.175 requiring that Part 135 flights be in a position to be able to land within the touchdown zone before leaving the published DA.

Figure 2-1 below illustrates the domain of this application. The ILS approach can be envisioned as containing three segments: instrument segment, SVS reference segment, and visual segment. The visual segment is fixed, beginning at 100 ft HAT and continuing to touchdown. Unaided visual contact with the landing environment is required. The instrument segment continues to 100 ft HAT. The SVS segment starts well before the CAT I DA as pilots observe the approaching runway and monitor agreement with localizer deviation, and continues to 100 ft HAT. At 100 ft HAT visual contact with the required cues must occur or a missed approach executed. The instrument and SVS segments are substantially overlapped, with the ILS navigation signal providing course guidance information and the SVS display runway awareness information.

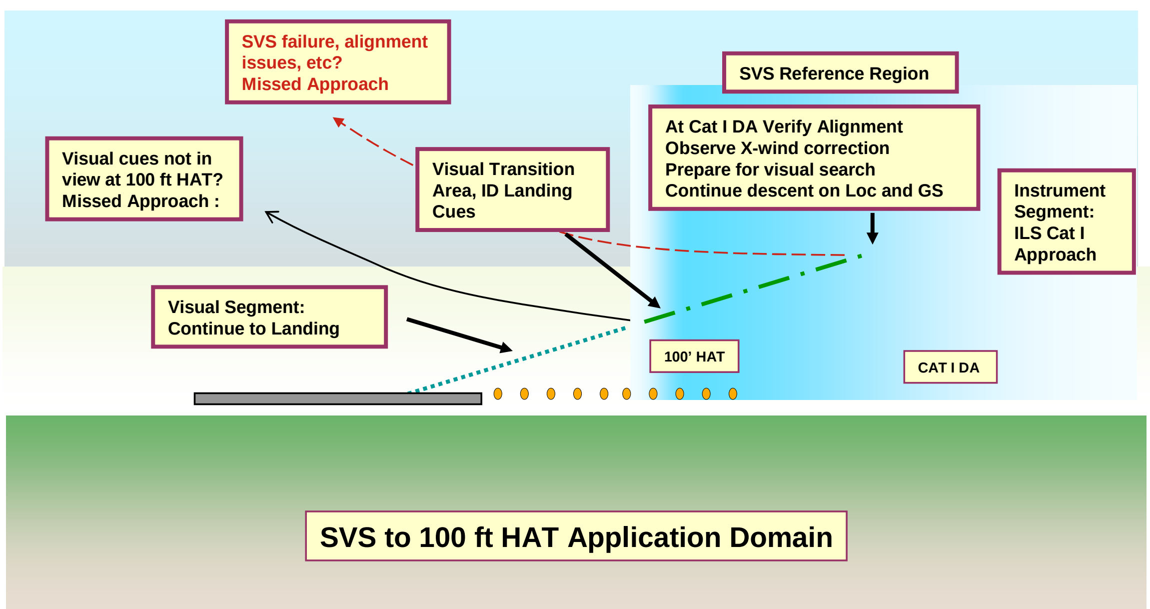

Figure 2-1. Use of SVS During ILS to 100 Feet HAT Application Domain

2.2 Availability of ILS Signal Below CAT I Minimum

This concept of operations assumes that pilots will be able to navigate using ground-based ILS to 100 ft HAT as authorized in 91.175 and as described in the previousdetail above. In order to assure this guidance will be provided to SVS users, FAA flight check data for CAT I ILS facilities will be used. All ILS CAT I facilities are flight checked to 100 ft HAT (Zone 3, 8200.1C), see Figure 2-2. If glideslope performance is not satisfactory below the Category I DA, a note will be placed on the Instrument Approach Procedure Chart advising “Glideslope unusable below 200 ft HAT.”

The FAA is currently in the process of flight checking all ILS systems through rollout, or point "E." The ILS facility is scored using a unique classification system that provides a comprehensive method of describing ILS performance. A character is assigned to the ILS according to the flight check results. This character defines the ILS point to which the localizer conforms to the Facility Performance CAT III course structure tolerances (A, B, C, T, D, or E) see Figure 2-2. The ILS is also given a number to indicate its level of integrity and continuity of service (1, 2, 3, or 4).

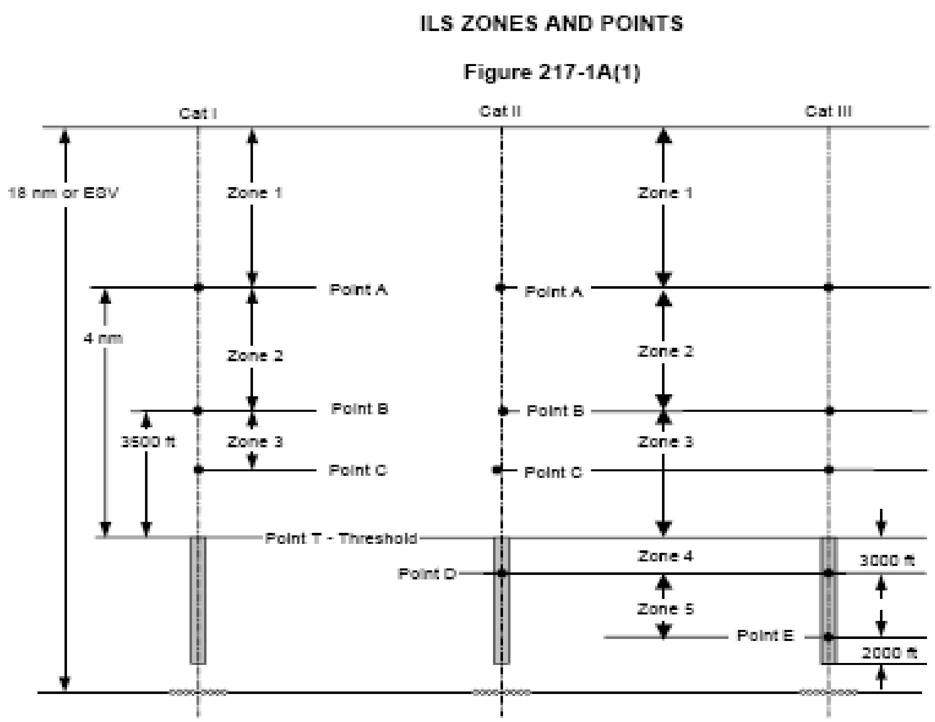

Figure 2-2. ILS Zones and Points for Performance Evaluation

The SVS to 100 ft HAT concept will require an ILS which conforms to International Civil Aviation Organization (ICAO) Annex 10 Facility Performance CAT I standards, has a localizer CAT III course structure to point "C," and conforms to the integrity and continuity of service objectives of Level 2 *[(2) Level 2 rated ILS equipment is used to support reduced visibility operations for which positioning guidance below 100 feet HAT is supplemented by other means, such as visual cues, FAA Order 6750.24D*]

Currently 85 facilities from a sample of 317 CAT I ILS facilities report to point "C" or better (26%). This percentage is expected to increase with new data processed from the latest flight check standard methods.

Section 3

The Concept of Operations: Use of the SVS Display to Support Straight-in Category I ILS Operations to 100 Feet HAT

The Concept of Operations described herein is to use an SVS display providing a cockpit display of the runway approach environment to permit operations below the existing CAT I ILS decision height of 200 ft HAT, based on the authorization provided in Part 91.175 (c)(3), described above. Minimum authorized visibility is initially expected to be runway visual range (RVR) 1800 ft.

For this concept, navigation guidance and associated deviation displays would be referenced to the ground-based ILS and the ILS is assumed to have the required performance to support operations to 100 ft HAT. The SVS display would use the wide-area augmentation system (WAAS) 3-D position of the aircraft in combination with terrain, obstacle and runway databases to render the displayed image of terrain, runways, and alignment features. Independence of navigation and display provides redundancy and enables crosschecking for accuracy. Use of ILS approach navigation should mitigate the integrity issues that would exist for WAAS operations below Cat I DA.

In applying the "continue on approach lights" authorization of (c)(3)(i), it is proposed that pilots may use the information from the SVS display in the same way that they use the information derived from seeing the approach lights through the windscreen. Specifically, the concept of operations proposes that the SVS display of the landing runway, with a runway centerline feature extending along the final approach course beginning at 3000 ft from the threshold and continuous to the runway (matching the standard length of the ALSF-II approach light system), provides information equivalent to actual visual contact with the approach lights. Of course, the SVS must satisfy appropriate accuracy and integrity requirements to meet this equivalence.[4] Approaching 200 ft (or the published DA) pilots would verify that ILS localizer and glideslope deviation are satisfactory, and that localizer deviation is congruent with the apparent runway centerline deviation on the SVS display.[5] If this requirement is met, pilots would be authorized to continue descent below the DA to 100 ft HAT, as they are currently authorized to do under FAR 91.175(c)(3)(i), based on visual

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[4] These criteria must be established through further analyses. How the confidence will be generated for this equivalence is a critical issue that will require additional attention through analysis, especially safety analysis, and adequate operational experience with use at DA(H) currently authorized.

[5] It may be feasible to automate this comparison and provide alert if the discrepancy exceeds a criterion value.

sighting of the approach light system. All other provisions of FAR 91.175 would remain in effect. At 100 ft HAT un-aided visual contact with one or more of the visual cues specified in 91.175(c)(3)(i through x) would be required, or a missed approach will be executed.

3.1 SVS Intended Functions

A statement of the intended function of a system such as SVS being installed, tested, and submitted for certification is normally the responsibility of the certification applicant. In the absence of submissions for approval of SVS for the purpose defined in this concept, a candidate definition of the intended function was created by MITRE/CAASD in order to assess the performance requirements, safety and operational suitability of this concept of operations.

There are two significant functions for SVS in this concept: verification of alignment with the landing runway prior to leaving the published DA, and improving pilot performance in making the transition from instrument flight to the visual cues required for final alignment, flare and landing.

3.1.1 Verifying Runway Alignment

As envisioned in this concept, one of the intended functions of the SVS display and its associated subsystems is to enable pilots to verify alignment with the runway centerline prior to descent below the published DA. The demonstrated accuracy of WAAS/GPS in the lateral plane is the enabling capability for this application. Based on the three most recent WAAS performance reports, lateral accuracy of the WAAS-enabled rendered runway and centerline information at 200 ft HAT can be expected to fall within ± 1.7 m laterally and 2.1 m vertically (95% confidence) when the minimum horizontal and vertical protection levels are available and WAAS precision approaches can be conducted. (FAA, 2006a, 2006b, 2005) Availability was greater than 96.5% at the worst performing test site (Los Angeles International Airport [LAX]).[6] A cross track error in the 2 m range would very likely be minimally detectable visually when actually sighting approach lights. Therefore, use of the runway centerline feature of the SVS display to substitute for approach lights should be feasible under the expected minimum authorized visibility of 1800 ft (RVR).

At 200 HAT (or higher CAT I DA) crosscheck of centerline display agreement with ILS localizer displacement and verification of alignment with the extended runway centerline would occur. A display of extended runway centerline from the runway threshold along the final approach path will enable the alignment task to be completed with cognitive efficiency and minimal mental workload. Conventional flight displays require focused attention and

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[6] This performance is based on approximately 2.3 x 10^7 samples at the "worst case" data collection site for each parameter, over the 9 months of data collection represented by the 3 reports.

interpretation to translate deviation indications into a mental model of aircraft position, while the SVS display integrates information in manner that supports direct perception of the current dynamic situation with respect to the approaching runway.

3.1.2 Improved Transition to the Visual Segment

The SVS display also provides a continuous, dynamic, 3-D rendered image of the approaching runway environment enabling anticipation of when the runway should become visible and very accurate guided visual search for the runway environment landing cues. The ability to predict future events, based on accurate perception and comprehension of the instantaneous system state is a hallmark of the highest level of situation awareness and the operational definition of "staying ahead of the airplane," to put it in pilot terms. Additional supporting discussion of situation awareness (SA) concepts underlying this part of the intended function are presented in Section 3.2.3 below.

3.2 Expanded Concept Description

In the following sections, a rationale is provided which links operational authorizations currently available under FAR 91.175 described above with the ability of the SVS display to support the runway acquisition task required under CAT I ILS operations. The display capability relies on the presence of certain display features, in particular, an extended runway centerline displayed along the final approach path to provide a functional equivalent of visual sighting of the approach lights.

3.2.1 Dynamic Presentation of Runway Awareness Information and Dynamic SA

The integration of information that is inherent in the SVS display is expected to significantly reduce cognitive workload during ILS approaches, and provide enhanced, easily interpreted runway awareness information. As the flight proceeds inbound to the airport, the displayed runway position increases in angular size to provide powerful awareness cues supporting the pilots' preparation for visual search. Crosswind corrections should be apparent as well. The runway and extended centerline features on the SVS display would enable pilots to predict exactly when and where the runway will appear in the windscreen.

This benefit may be enhanced by the use of a pathway guidance feature which has been shown in prior research to provide two significant benefits; reduced flight technical (tracking) error through an intuitive display of tracking performance, and increased predictive SA, especially along routes where turn maneuvers can be displayed in a manner that enables anticipation of the required maneuvering.

Flight technical performance is also enhanced by the use of a flight path vector (FPV) display feature that integrates instantaneous aircraft state data and presents it as a cue which projects the current flight path to a point in visual field. Pilots using current technology head up displays (HUDs) maneuver their aircraft such that the FPV will intercept the desired touchdown point on the runway visible through the collimated HUD image, or the runway outline image derived from a database. A similar feature could be provided on an SVS head down display (HDD), combined with a “follow-me” target symbol representing command guidance information. Using appropriate maneuvers to place the FPV symbol over the command guidance cue results in an accurate track along the desired path. Figure 1-1 above, shows both the FPV cue (circular feature in white at the center of the display) with a command guidance cue (circular feature in magenta).

3.2.2 Cognitive Benefits

It is generally accepted that the runway landing environment must be in view for about 3 seconds for pilots to determine cross track and vertical deviation errors with respect to the planned landing trajectory (Gallagher, 2002). It is expected that the precise visual search guidance that will be enabled by accurate depiction of the runway environment on the SVS display, including runway offset due to crosswinds, will shorten visual acquisition time.

Since the information in the SVS display is provided as a dynamic, spatial depiction, the cognitive workload of interpreting the meaning of localizer and glideslope deviation, and distance remaining to threshold should be reduced. The compatibility of the spatially displayed representation of the runway environment with the visual-spatial task of detecting and spatially processing the visual cues required for flare and landing is the enabler for SA provided by the SVS system (Wickens & Andre, 1992; Prinzel, Kramer, Arthur, Bailey, & Comstock, 2005).

Such advance information on runway location is expected to reduce visual acquisition time leading to more accurate flare judgment, more intuitive awareness of crosswind condition, increased safety, and support a smooth transition from head down instrument cues to head up visual cues for the flare and landing.

3.2.3 General SA Concept

In addition to the cognitive processing advantages provided by SVS display it also supports robust SA as described by Endsley (2000). In the Endsley SA model, the highest level of SA is “projection” in which flight crews not only understand the current state, but also can reliably project that understanding to a range of possible future states, enabling smooth execution of required future tasks. That anticipation (“staying ahead of the airplane”) is a hallmark of skilled task performance, and is particularly valuable in dynamic systems such as aircraft. SVS displays are inherently dynamic and future oriented, directly supporting the deepest level of SA for crews, in this case with respect to the visual acquisition task which must be completed at the end of an ILS approach.

NASA research has also documented enhanced situational awareness arising from the use of SVS displays, compared to conventional displays (Prinzel, Kramer, Arthur, Bailey & Comstock, 2005). In a flight test evaluation of an integrated SVS system display formats, pilots rated their approach[7] operations SA higher in the 2 SVS display conditions than in the baseline conventional instrument condition.

As previously described, the lateral and vertical accuracy of the WAAS-enabled rendered image will be within ± 1.7 m laterally and 2 m vertically 95% of the time. Errors of this magnitude would not be expected to have a significant effect on visual search performance and are not a factor for navigation on the flight path, which continues to be provided by ILS. Errors exceeding a certain threshold value (which are TBD) at which the visual performance would be affected may require an alert.

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[7] And surface.

Section 4

Requirements

4.1 Automation and Guidance Requirements

The navigation source for this application is a conventional, ground-based ILS approach. Any path deviation used to drive a guidance system (e.g., flight director or pathway display) would be referenced to the ILS signal. If autopilot is determined to be required to achieve the desired trajectory performance, it would be referenced to ILS data.

CAT I ILS approaches do not normally require autopilot or flight director, but air carrier operations specifications may require at least one of these to be approved to operate at the lowest available DA. (FAA, 2002). In addition, air carrier and commercial operations require a minimum runway visual range report above a specified value to commence an ILS approach. It is expected that this concept would be approved at the CAT I visibility limit of RVR 1800 to correspond with current Joint Airworthiness Authority initiatives to harmonize approach visibility criteria.

One automation function that may provide benefit, given that dual navigation sources are used to implement the concept, is an automated comparison of the ILS deviation with the deviations computed by the WAAS navigation system. If the comparator system sensed a difference in excess of a criterion value, it would alert the pilot or crew. This will in turn require that for each ILS runway to be used, that a WAAS approach be available to construct a companion trajectory for comparison purposes. This also suggests a requirement for determining the deviation criterion that would be used to fire the alert. The alerting system design would have to take into account “normal” ILS beam and WAAS tracking anomalies to minimize the occurrence of false alerts. When the alert is present the authorization to descend below published CAT I DA would be rescinded. At the CAT I DA if none of the visual cues in 91.175 (c)(3) was clearly visible with un-aided vision, then a missed approach would be required.

4.2 ILS System Performance Requirements

The concept of operations assumes that pilots will continue to navigate by reference to the ILS during the descent from CAT I DA to 100 ft HAT. Part 91.175 specifies no guidance requirements other than visual sighting of the outer portion of the approach light system (or other specified features associated with the runway landing environment) as authorization to begin descent. When using the SVS display to substitute for approach lighting, it will be necessary to establish that the localizer and glideslope signals will support navigation to 100 ft HAT. It is expected that ILS critical area protection would have to be maintained, with appropriate surface markings identifying critical areas. The means of assuring compliance with ILS hold lines will need to be determined, but could include a requirement for an operating control tower, or a Cockpit Display of Traffic Information (CDTI) to provide the crew with awareness of surface traffic.

4.3 SVS Display System Requirements

The SVS display system is an integrated combination of several elements including WAAS position in space, terrain and runway databases, aircraft state information, (airspeed, altitude, heading, vertical speed, horizon reference) and the associated display processing capability. Other database information, which may include cultural features such as obstacles, runways, runway markings, and possibly lighting configuration may be considered, with runways and associated features an essential element of this concept of operations. Display of aircraft state and flight control data would be integrated with the SVS display, following the guidelines contained in AC 23-26. This section discusses some of its major components.

4.3.1 Display Type

Display type is an important implementation issue, with both HUD and HDD options to be considered. Cost and retrofit issues must be considered. (Prinzel, Arthur, & Bailey, 2005)

Using HUD equipment to display the SVS data will minimize the transition from heads down to the out-of-the-window scan required at 100 ft. On the other hand, the level of detail in the HUD SVS image may have to be reduced to ensure that primary flight control information is still clearly visible, while continuing to provide the terrain and runway awareness benefits afforded by the SVS. The balance between reduced SVS information (including the loss of color coding of SVS information) and utility of that information will need to be determined.

If a single HUD implementation is chosen on the Captain's side of the cockpit, a potential issue of crew coordination is created in multi-crew aircraft, if the First Officer does not have access to the same visual information as the Captain. In this case, a HDD implementation on the First Officer display may be advantageous. Practical operational questions regarding crew coordination in augmented vision environments have not been explicitly studied, and procedures should be developed to support these technologies.

If an HDD is selected, the performance of the crew in making the transition from head down reliance on the SVS, to detection and processing of the runway environment will need to be assessed. The assertion that the transition to external cues using SVS on a head down display (HDD) is more efficient than with conventional displays, should be subject to experimental evaluation. Other human performance issues related to displays are outlined in Section 5.

4.3.2 Display Field of View

In this application, the SVS display will be used to provide alignment and distance to threshold information created from the synthesis and integration of the WAAS position in space with terrain and runway feature databases. Pilots will refer to this display to estimate distance remaining to touchdown, magnitude of crosswind correction, and alignment with the extended runway centerline approaching the published DA. Pilots will also verify agreement between ILS localizer deviation and apparent track toward the runway displayed in the SVS view. This information will then be used to guide visual search for the runway environment.

These judgments, especially the dynamic distance to go, may be affected by the display field of view selected. One of the parameters of field of view that has been found to affect spatial judgments is the “zoom” scale of the display compared to the same view seen through the windscreen. Several studies have indicated that a slight magnification of the synthetic view is typically required to produce a judgment of “conformality” by pilot observers. Roscoe (1984) reports on an early study of an optical periscope display used to maneuver an airplane all the way to touchdown. Roscoe found that a magnification factor of 1.2 (“zoomed in”) yielded performances very close to that achieved with normal vision in the landing task. At a magnification factor of 2.0 undershoots resulted; at a minification factor of 0.86 overshoots occurred. Similar findings have been found in static trials of image matching with a real world external scene (Meehan & Triggs, 1988).

An appropriate field of view to support the visual acquisition task must be selected in the system design.

4.3.3 Extended Centerline Feature

The extended runway centerline is an essential feature for this concept, directly substituting for approach lighting. The exact requirements for how the centerline is depicted will need to be determined through research. For example, one may imagine different implementations of such an alignment feature ranging in complexity from a single straight line of sufficient line weight to be easily visible, to a representation of an actual approach light system including lateral roll guidance features, side row features and threshold termination. Another approach might be to replicate the actual approach lights that the runway has, reserving the more abstract implementations for the few ILS approaches with no approach lights installed. The Radio Technical Commission for Aeronautics (RTCA) guidance on electronic mapping databases explicitly considers the possibility that surface lighting may be represented in mapping databases (RTCA, 2001).

4.3.4 Pathway Display

SVS pathway displays (refer to Figure 1-1 in Section 1) have been demonstrated to significantly reduce flight technical error. Previous NASA research in SVS technology has demonstrated improved tracking performance while flying in terrain-constrained environments, and during missed approach, where the predictive cues provided by pathway displays would have a significant benefit to performance (Prinzel, Kramer, Arthur, Bailey, & Parrish, 2004). Tracking performance is consistently demonstrated to be improved when pilots are using a pathway display, especially along paths requiring a significant number of maneuvers where the predictive power of the path depiction provides excellent predictive SA (Dougherty & Wickens, 2002).

Benefits to an approach application in low visibility while flying a straight-in approach segment are less well studied, but subjects have reported that care would be required in designing the pathway elements in such a manner so as not to obscure essential runway or centerline features that support the alignment and runway awareness tasks. It will be important to design a display which provides the correct balance between good tracking performance, alignment awareness, and a high quality view of the approaching runway to support the transition to visual landing.

4.3.5 Display Size

Regardless of display modality the selection of features to be included must be carefully considered so as not to overwhelm the essential supportive features that enable the concept, a clear depiction of the runway and its associated centerline feature. Standard aircraft control instrumentation will of course, be included following both certification requirements and industry standard practices. Methods must be available to declutter the display when required.

The SVS egocentric viewpoint is rendered in real time and updated in accordance with the requirements of AC23-26 (FAA, 2005) or equivalent guidance for transport category aircraft when it is developed. SVS terrain and cultural database integrity is verified through compliance with the appropriate minimum operational performance standard (MOPS) requirements (see RTCA, 2001 & 2002a).

Minimum display size required to support this application must be determined from analysis, simulation and flight test.

Section 5

Human Performance

Human performance requirements must be accounted for in the implementation of the procedure. For example, while the expected accuracy of the SVS lateral display is very high, with high availability, it is remotely possible that the error could be close to the existing Horizontal Protection Level (HPL, 40 m) for WAAS precision approaches. The mitigation for this error must be detection of the difference between the aircraft position and the displayed position. In this concept, the aircraft is navigating along the ILS localizer and glideslope and thus should still be aligned with the runway. However, the display of runway position could now be in error by as much as 40 m. The performance issue would be the cognitive discrepancy between the displayed and actual position of the runway, and what the effect of that discrepancy might have on runway detection, flare, and landing performance. At issue, is the cognitive demand of resolving the discrepancy visually if it exists, and whether that process will delay assessment of whether a safe landing can be completed.

The amount of discrepancy between localizer deviation and SVS display depiction that can be detected is currently not known. Also unknown is the magnitude of discrepancy that results in a deterioration in the visual acquisition, flare, and landing performance. With two sources of deviation data available, one could envision an automatic comparison of deviation, which would alert the pilot at a deviation value that approaches the limit of continued good visual detection performance. While the probability of a near-HPL display offset will be very small, determining an acceptable limit value would provide the basis for an alert based on the comparison between ILS and WAAS navigation solutions. Typical ILS and WAAS navigation errors would have to be taken into account. Note that we are not mitigating an actual aircraft deviation from desired trajectory, but accounting for possible mismatch between displayed and actual position.

5.1 Landing Performance

For purposes of evaluating this application of SVS it may be useful to define a target level of performance that would permit an assessment of a pilot's ability to safely conduct the operation. While approach containment and landing performance requirements are not specified for CAT I operations, except for commercial operations who are required to be able to land in the touchdown zone, the guidelines for automatic landing performance (FAA, 1999) could be used to provide criteria to assess the safety of this application. Language contained in both AC 120-29 and AC 120-28 suggests an approach to performing such an assessment. AC 120-29 broadly defines "normal maneuvering," as referred to in 91.175:

> "Normal maneuvers typically do not involve use of bank angles greater than 30 degrees, pitch attitudes in excess of 25 degrees nose up or 10 degrees nose down, or

sink rates in excess of 1100 ft per minute below 500 ft HAT while maneuvering to land within the touchdown zone, during go-around, or during a rejected landing. During a missed approach, pitch attitudes in excess of +30 degrees or bank angles greater than 30 degrees would typically be considered excessive."

AC 120-28D (FAA, 1999), sets out requirements for CAT III operational approval. While the present concept is expected to be conducted in weather conditions well above CAT III minima, the language defining a "safe landing" in relation to touchdown performance could be applied in assessing the SVS concept of operations. A safe landing in the touchdown zone may be assumed, if the following performance from AC 120-28D (FAA, 1999) is achieved (See Figure 5-1):

(a) Longitudinal touchdown no earlier than a point on the runway 200 ft (60 m) from the threshold,

(b) Longitudinal touchdown no further than 2700 ft (1000 m) from the threshold e.g., not beyond the end of the touchdown zone lighting (if installed),

(c) Lateral touchdown with the outboard landing gear within 70 ft (21 m) from runway centerline. (These values assume a 150 ft (45 m) runway. The lateral touchdown performance limit may be appropriately increased if operation is limited to wider runways).

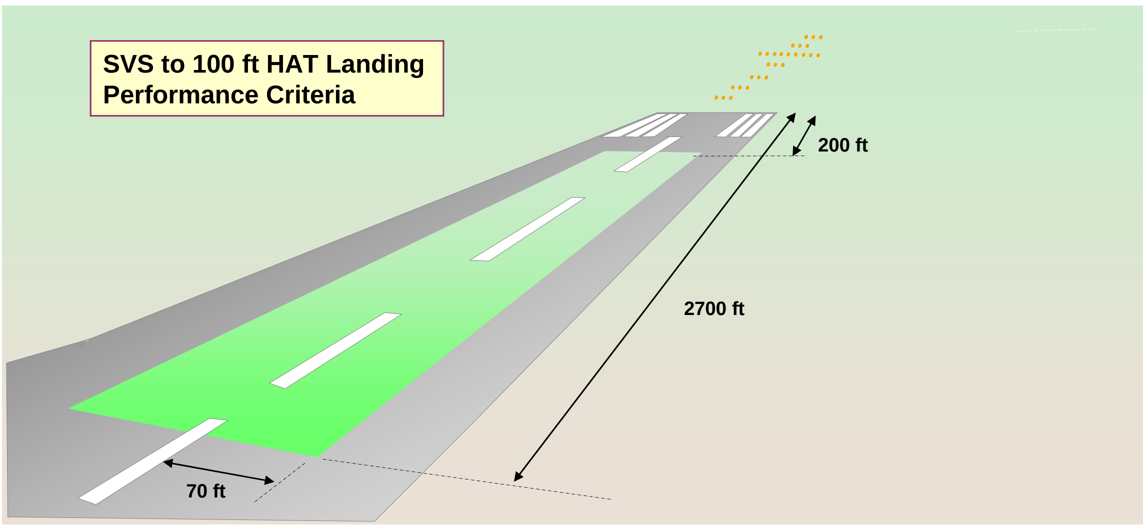

Figure 5-1. SVS to 100 ft HAT Potential Landing Performance Criteria

Section 6

Database Accuracy and Integrity Requirements

Requirements for the use of aeronautical databases have been published by RTCA, addressing both terrain and obstacle databases (RTCA 2002), and databases to support mapping of cultural features (RTCA 2001) as described in this concept of operations. In addition, data interchange standards have also been developed in conjunction with the European Organization for Civil Aviation Equipment (EUROCAE) Working Group 44 (RTCA 2004) to establish an international consensus on the use of such data so that seamless worldwide operations can be assured.

The RTCA documents identify the potential applications that were explicitly considered in the preparation of the guidance material. This included potential use in synthetic vision systems. Both the terrain and obstacle guidance in DO-272C (RTCA 2002) and the aerodrome mapping requirements in DO-276 (RTCA 2001) considered that applications to SVS may be supported. However, at the publication date of DO-272C the requirements for lateral and vertical terrain resolution supporting SVS had not yet been determined, due to the relative immaturity of SVS technology and its application to low visibility approach operations. These requirements will have to be established.

DO-276 (RTCA 2001), specifies three levels of resolution that support different types of applications, Fine, Medium, and Coarse. It envisions that surface and near-surface operations using this data will require Fine resolution, with a horizontal and vertical accuracy of 0.1 m for most features, and 0.01 m for markings such as centerlines and touchdown zones. Angular accuracy requirements for runway related data (e.g., runway bearing) are also specified (accuracy 0.1°, with a resolution of 0.01°), which would support runway and extended centerline depiction as described in this concept of operations. Provision is made for a full range of supplemental database elements such as, surface lighting and runway markings, which may enhance the display of the runway environment to support this concept. The resolution requirements for these features are not yet specified.

Section 7

Non-Normal Events

Procedures for addressing non-normal events must be developed. Any failure of SVS display input source data (loss of WAAS signal in space, Horizontal Alert Limit flag, loss of heading source, other hardware failure, etc) would terminate the authorization to descend below published DA using SVS display features in lieu of approach lights. In this case, descent below published DA would require that unaided visual contact with the landing environment be established at the published DA. If such a failure occurs after passing the published DA, but prior to 100 ft HAT, an immediate missed approach would be required, unless unaided visual contact with the landing environment has been established.

It is expected that there will be maximum limits for lateral deviations beyond which a successful visual landing will not be possible. Deviations beyond these values (which are TBD) may require operational limitations that would mandate a missed approach. The limiting deviations normally used for CAT I and II operations could be considered for guidance.

Section 8

Issues for Future Research

This section summarizes some of the issues that have been raised in conjunction with this application, and questions are formed to suggest possible future research.

8.1 Displays

1. What is the optimum field of view to support the runway acquisition task?
2. Is a HUD required for safe operations using SVS display with ILS approach during operations to 100 ft HAT?
3. What is the optimum terrain elevation data display rendering mode for HUD? For HDD?
4. What is the minimum display size required to support the SVS to 100 ft with ILS approach application?
5. What is the optimum configuration for the extended runway centerline feature proposed in this concept of operations?
6. Will pathway guidance be required?
7. Will alerts be required for cross deviation assessment? For exceeding maximum lateral deviation for an acceptable landing?
8. Will a radar altimeter be required to determine height above touchdown, even though this is a CAT I operation?

8.2 Human Performance/Human Factors

1. Attention capture. Will SVS displays disrupt awareness of other critical events in the operating environment, (e.g., altitude awareness, traffic awareness, terrain awareness)
2. Is there a significant likelihood of intentional misuse (e.g., will pilots attempt to use the display below 100 HAT)?
3. What is the maximum lateral and vertical offset from the published approach trajectory that will permit a safe landing in the touchdown zone?
4. What is the minimum detectable discrepancy between current localizer and glideslope position and displayed position?

8.3 Databases

1. What is the optimum terrain database resolution during the final approach phase of flight?

2. Which obstacles must be included in the obstacle database that are loaded with an instrument approach?
3. What specifications need to be developed to support other database requirements (e.g., runway features, lighting representation)?
4. Is internal database validation sufficient for certification, or will external sensor validation be required?
5. Will external sensor validation be required to validate runway alignment in the ILS with SVS approach concept?
6. Can radar altitude input be used to mitigate SVS display vertical integrity deficiencies during ILS approach?

8.4 Operations

1. What operational procedures will be required to ensure obstacle clearance during missed approach from below the CAT I DA?
2. How will ILS Critical area protection be assured during low visibility operations using this concept of operations? Will a staffed Control Tower be required?
3. What training will be required for Air Carrier and General Aviation flight crew to safely conduct the concept of operations?
4. Can this concept be performed by a single pilot, or are two pilots required?
5. What level of automation support is required for this concept? Flight director? Autopilot?
6. If HUD is required for the Captain, is an HDD presentation required for the First Officer to retain crew SA and proper crew resource management (CRM)?
7. What operational procedures are necessary when discrepancies between localizer deviation and SVS display are detected?

8.5 Regulatory and Programmatic

1. How will the FAA determine if the integrity requirements for the database and the overall SVS system to meet the intended function are met? Will operational SVS experience at current DA(H) help?
2. Will additional incremental steps be required to build the operational experience and data to support the proposed procedure? If so, what should they be?
3. Will the operational requirements be different for Part 91 vs. Part 121, and Part 135 operators? If so, how?

Section 9

Other Approaches

This concept of operations has described use of SVS during approach to runways already served by a conventional ILS approach. The development and deployment of GPS and WAAS is intended to bring CAT I ILS performance to a much larger set of runways.

Combining the precision WAAS navigation with the SVS display will bring precision low visibility operations to a much larger selection of airports, but there will be significant issues to address. There are two primary hurdles in applying SVS technology as described in this concept of operations to other approaches supported by GPS and WAAS. The first is that the integrity required by current standards (DO-229C) cannot be achieved with WAAS alone. Local Area Augmentation Systems may provide the required performance, but development and deployment of local area augmentation system (LAAS) ground stations on a wide scale has not yet been authorized. This fact will affect the ability to apply SVS technology to reduce operating minima unless mitigations for the integrity issues can be put in place. The approaches that are affected include:

1. GPS landing system (GLS) (CAT I equivalent)

2. Lateral and vertical approach (LPV) (localizer precision with vertical guidance)

3. Lateral navigation (LNAV)/Vertical navigation (VNAV)

4. Non-vertically guided non-precision approaches.

Until integrity of the navigation signal can be assured or deficiencies mitigated by other means, lower approach minima may not be possible using SVS display. However, the workload reduction and SA benefits of SVS would still be available, and the precision guidance for visual search for the runway environment could improve reliability of operations.

A related issue is the lack of independence between display source and navigation source. Whether it is acceptable to use WAAS position as a common source of data for both functions will have to be determined.

Other augmented vision technologies such as Enhanced Flight Vision Systems may be able to provide additional capability, especially if combined with SVS. (Prinzel, Kramer, Arthur, Bailey & Comstock, 2005; Arthur, Kramer, & Bailey, 2004) Benefits and applications of integrated display capability combining both EFVS and SVS will be fruitful area for future research.

Section 10

Summary and Conclusions

This paper has described an concept of operations for the use of SVS display technology with CAT I, straight in ILS approach. The concept uses the current authorization available under Part 91.175 of the FAR to begin descent from the published DA, based solely on a visual contact with approach lights. It proposes the use of an extended centerline depiction on the SVS as an equivalent to the visual acquisition of the approach lights. Appropriate integrity requirements would have to be met by the SVS to claim such equivalence.[8] Descent below 100 ft HAT would not be allowed unless other visual cues associated with the runway environment are clearly visible and identifiable by the pilot.

A substantial body of research has already been completed which has demonstrated the potential utility of SVS displays in increasing performance and SA, while reducing workload. Issues and areas for additional research have been identified or amplified. Additional analyses and discussions with government and industry stakeholders regarding this application and associated issues are recommended. A further decomposition into interim program steps of smaller operational credits may be beneficial.

8 An adequate degree of operational experience under current minima may be required to generate the necessary basis to authorize such equivalence.

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Appendix

14 Code of Federal Regulations (CFR) 91.175

A.1 Takeoff and Landing Under Instrument Flight Rules (IFRs)

(a) *Instrument approaches to civil airports.* Unless otherwise authorized by the Administrator, when an instrument letdown to a civil airport is necessary, each person operating an aircraft, except a military aircraft of the United States, shall use a standard instrument approach procedure prescribed for the airport in Part 97 of this chapter.

(b) *Authorized decision height (DH) or minimum descent altitude (MDA).* For the purpose of this section, when the approach procedure being used provides for and requires the use of a DH or MDA, the authorized DH or MDA is the highest of the following:

(1) The DH or MDA prescribed by the approach procedure.

(2) The DH or MDA prescribed for the pilot in command.

(3) The DH or MDA for which the aircraft is equipped.

[(c) Operation below DH or MDA. Except as provided in Paragraph (l) of this section, where a DH or MDA is applicable, no pilot may operate an aircraft, except a military aircraft of the United States, at any airport below the authorized MDA or continue an approach below the authorized DH unless-- **]**

(1) The aircraft is continuously in a position from which a descent to a landing on the intended runway can be made at a normal rate of descent using normal maneuvers, and for operations conducted under Part 121 or Part 135 unless that descent rate will allow touchdown to occur within the touchdown zone of the runway of intended landing;

(2) The flight visibility is not less than the visibility prescribed in the standard instrument approach being used; and

(3) Except for a Category (CAT) II or CAT III approach where any necessary visual reference requirements are specified by the Administrator, at least one of the following visual references for the intended runway is distinctly visible and identifiable to the pilot:

(i) The approach light system, except that the pilot may not descend below 100 ft above the touchdown zone elevation using the approach lights as a reference unless the red terminating bars or the red side row bars are also distinctly visible and identifiable.

(ii) The threshold.

(iii) The threshold markings.

(iv) The threshold lights.

(v) The runway end identifier lights.

(vi) The visual approach slope indicator.

(vii) The touchdown zone or touchdown zone markings.

(viii) The touchdown zone lights.

(ix) The runway or runway markings.

(x) The runway lights.

(d) Landing. No pilot operating an aircraft, except a military aircraft of the United States, may land that aircraft when:

(1) For operations conducted under paragraph (l) of this section, the requirements of (l)(4) of this section are not met; or

(2) For all other Part 91 operations and Parts 121, 125, 129, and 135 operations, the flight visibility is less than the visibility prescribed in the standard instrument approach procedure being used.

(e) *Missed approach procedures.* Each pilot operating an aircraft, except a military aircraft of the United States, shall immediately execute an appropriate missed approach procedure when either of the following conditions exist:

(1) Whenever operating an aircraft pursuant to Paragraph (c) or (l) of this section and the requirements of that paragraph are not met at either of the following times:

(i) When the aircraft is being operated below MDA; or

(ii) Upon arrival at the missed approach point, including a DH where a DH is specified and its use is required, and at any time after that until touchdown.

(2) Whenever an identifiable part of the airport is not distinctly visible to the pilot during a circling maneuver at or above MDA, unless the inability to see an identifiable part of the airport results only from a normal bank of the aircraft during the circling approach.

(f) *Civil airport takeoff minimums.* Unless otherwise authorized by the Administrator, no pilot operating an aircraft under Parts 121, 125, 129, or 135 of this chapter may take off from a civil airport under instrument flight rule (IFR) unless weather conditions are at or above the weather minimum for IFR takeoff prescribed for that airport under Part 97 of this chapter. If takeoff minimums are not prescribed under Part 97 of this chapter for a particular airport, the following minimums apply to takeoffs under IFR for aircraft operating under those parts:

(1) For aircraft, other than helicopters, having two engines or less--1 statute mi visibility.

(2) For aircraft having more than two engines-- ½ statute mi visibility.

(3) For helicopters-- ½ statute mi visibility.

(g) *Military airports.* Unless otherwise prescribed by the Administrator, each person operating a civil aircraft under IFR into or out of a military airport shall comply with the instrument approach procedures and the takeoff and landing minimum prescribed by the military authority having jurisdiction of that airport.

(h) *Comparable values of runway visual range (RVR) and ground visibility.*

(1) Except for CAT II or CAT III minimums, if RVR minimums for takeoff or landing are prescribed in an instrument approach procedure, but RVR is not reported for the runway of intended operation, the RVR minimum shall be converted to ground visibility in accordance with the table in Paragraph (h)(2) of this section and shall be the visibility minimum for takeoff or landing on that runway.

(2)

RVR (feet)	Visibility (statute mile)
1,600	¼
2,400	½
3,200	⅝
4,000	¾
4,500	⅞
5,000	1
6,000	1¼

(i) Operations on unpublished routes and use of radar in instrument approach procedures. When radar is approved at certain locations for air traffic control (ATC) purposes, it may be used not only for surveillance and precision radar approaches, as applicable, but also may be used in conjunction with instrument approach procedures predicated on other types of radio navigational aids. Radar vectors may be authorized to provide course guidance through the segments of an approach to the final course or fix. When operating on an unpublished route or while being radar vectored, the pilot, when an approach clearance is received, shall, in addition to complying with Sec. 91.177, maintain the last altitude assigned to that pilot until the aircraft is established on a segment of a published route or instrument approach procedure unless a different altitude is assigned by ATC. After the aircraft is so established, published altitudes apply to descent within each succeeding route or approach segment unless a different altitude is assigned by ATC. Upon reaching the final approach course or fix, the pilot may either complete the instrument approach in accordance with a procedure approved for the facility or continue a surveillance or precision radar approach to a landing.

(j) *Limitation on procedure turns.* In the case of a radar vector to a final approach course or fix, a timed approach from a holding fix, or an approach for which the procedure specifies "No procedure turn (PT)," no pilot may make a PT unless cleared to do so by ATC.

(k) Instrument landing system (*ILS) components.* The basic ground components of an ILS are the localizer, glide slope, outer marker, middle marker, and, when installed for use with CAT II or CAT III instrument approach procedures, an inner marker. A compass locator or precision radar may be substituted for the outer or middle marker. Distance measuring equipment (DME), very high frequency omnidirectional range (VOR), or nondirectional beacon fixes authorized in the standard instrument approach procedure or surveillance radar may be substituted for the outer marker. Applicability of, and substitution for, the inner marker for CAT II or III approaches is determined by the appropriate Part 97 approach procedure, letter of authorization, or operations specification pertinent to the operations.

(l) Approach to straight-in landing operations below DH, or MDA using an enhanced flight vision system (EFVS). For straight-in instrument approach procedures other than CAT II or CAT III, no pilot operating under this section or Sections 121.651, 125.381, and 135.225 of this chapter may operate an aircraft at any airport below the authorized MDA or continue an approach below the authorized DH and land unless—

(1) The aircraft is continuously in a position from which a descent to a landing on the intended runway can be made at a normal rate of descent using normal maneuvers, and, for operations conducted under Part 121 or Part 135 of this chapter, the descent rate will allow touchdown to occur within the touchdown zone of the runway of intended landing;

(2) The pilot determines that the enhanced flight visibility observed by use of a certified enhanced flight vision system is not less than the visibility prescribed in the standard instrument approach procedure being used;

(3) The following visual references for the intended runway are distinctly visible and identifiable to the pilot using the enhanced flight vision system:

(i) The approach light system (if installed); or

(ii) The following visual references in both Paragraphs (l)(3)(ii)(A) and (B) of this section:

(A) The runway threshold, identified by at least one of the following:

(1) The beginning of the runway landing surface;

(2) The threshold lights; or

(3) The runway end identifier lights.

(B) The touchdown zone, identified by at least one of the following:

(1) The runway touchdown zone landing surface;

(2) The touchdown zone lights;

(3) The touchdown zone markings; or

(4) The runway lights.

(4) At 100 ft above the touchdown zone elevation of the runway of intended landing and below that altitude, the flight visibility must be sufficient for the following to be distinctly visible and identifiable to the pilot without reliance on the enhanced flight vision system to continue to a landing:

(i) The lights or markings of the threshold; or

(ii) The lights or markings of the touchdown zone;

(5) The pilot(s) is qualified to use an EFVS as follows—

(i) For Parts 119 and 125 certificate holders, the applicable training, testing and qualification provisions of Parts 121, 125, and 135 of this chapter;

(ii) For foreign persons, in accordance with the requirements of the Civil Aviation Authority of the State of the operator; or

(iii) For persons conducting any other operation, in accordance with the applicable currency and proficiency requirements of Part 61 of this chapter;

(6) For Parts 119 and 125 certificate holders, and Part 129 operations specifications holders, their operations specifications authorize use of EFVS; and

(7) The aircraft is equipped with, and the pilot uses, an enhanced flight vision system, the display of which is suitable for maneuvering the aircraft and has either an Federal Aviation Administration (FAA) type design approval or, for a foreign-registered aircraft, the EFVS complies with all of the EFVS requirements of this chapter.

(m) For purposes of this section, "EFVS" is an installed airborne system comprised of the following features and characteristics:

(1) 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;

(2) The EFVS sensor imagery and aircraft flight symbology (i.e., at least airspeed, vertical speed, aircraft attitude, heading, altitude, command guidance as appropriate for the approach to be flown, path deviation indications, and flight path vector, and flight path angle reference cue) are presented on a head-up display (HUD), or an equivalent display, so that they are clearly visible to the pilot flying in his or her normal position and line of vision and looking forward along the flight path, to include:

(i) The displayed EFVS imagery, attitude symbology, flight path vector, and flight path angle reference cue, and other cues, which are referenced to this imagery and external scene topography, must be presented so that they are aligned with and scaled to the external view; and

(ii) The flight path angle reference cue must be displayed with the pitch scale, selectable by the pilot to the desired descent angle for the approach, and suitable for monitoring the vertical flight path of the aircraft on approaches without vertical guidance; and

(iii) The displayed imagery and aircraft flight symbology do not adversely obscure the pilot's outside view or field of view through the cockpit window;

(3) The EFVS includes the display element, sensors, computers and power supplies, indications, and controls. It may receive inputs from an airborne navigation system or flight guidance system; and

(4) The display characteristics and dynamics are suitable for manual control of the aircraft.

Glossary

AC	Advisory Circular
ALSF	Approach Lighting with Sequenced Flashing Lights
ATC	Air Traffic Control
CAASD	Center for Advanced Aviation System Development
CAT	Category
CDTI	Cockpit Display of Traffic Information
CFR	Code of Federal Regulations
CRM	Crew Resource Management
DA	Decision Altitude
DA(H)	Decision Altitude Height
DH	Decision Height
DME	Distance Measuring Equipment
EFVS	Enhanced Flight Vision Systems
EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulations
FPV	Flight Path Vector
GLS	Global Landing System
GPS	Global Positioning System
HAT	Height Above Touchdown
HDD	Head Down Display
HPL	Horizontal Protection Level
HUD	Head Up Display
ICAO	International Civil Aviation Organization
IFR	Instrument Flight Rule
ILS	Instrument Landing System

LAAS	Local Area Augmentation System
LNAV	Lateral Navigation
LPV	Lateral and Vertical Approach
MDA	Minimum Descent Altitude
MOPS	Minimum Operational Performance Standard
NASA	National Aeronautics and Space Administration
NGATS	Next Generation Air Transportation System
NIA	National Institute of Aerospace
PT	Procedure Turn
RTCA	Radio Technical Commission for Aeronautics
RVR	Runway Visual Range
SA	Situation Awareness
SVS	Synthetic Vision System
VNAV	Vertical Navigation
VOR	Very High Omnidirectional Range
WAAS	Wide Area Augmentation System