

# **Concept of Operations for Commercial and Business Aircraft Synthetic Vision Systems**

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## Abstract

A concept of operations (CONOPS) for the Commercial and Business (CaB) aircraft synthetic vision systems (SVS) is described. The CaB SVS is expected to provide increased safety and operational benefits in normal and low visibility conditions. Providing operational benefits will promote SVS implementation in the fleet, improve aviation safety, and assist in meeting the national aviation safety goal. SVS will enhance safety and enable consistent gate-to-gate aircraft operations in normal and low visibility conditions. The goal for developing SVS is to support operational minima as low as Category IIIb in a variety of environments. For departure and ground operations, the SVS goal is to enable operations with a runway visual range of 300 feet. The system is an integrated display concept that provides a *virtual visual environment*. The SVS virtual visual environment is composed of three components: an enhanced intuitive view of the flight environment, hazard and obstacle detection and display, and precision navigation guidance. The virtual visual environment will support enhanced operations procedures during all phases of flight — ground operations, departure, en route, and arrival. The applications selected for emphasis in this document include low visibility departures and arrivals including parallel runway operations, and low visibility airport surface operations. These particular applications were selected because of significant potential benefits afforded by SVS.

## Executive Summary

This document describes an initial concept of operations (CONOPS) for commercial and business aircraft (CaB) synthetic vision systems (SVS). It is a “living document” which will be modified as the CaB SVS CONOPS is refined. It is intended to provide a continued operational focus for CaB SVS research, development, and implementation and to describe how air carriers will use SVS technologies. While the focus of this effort is in the civil and corporate air transport arenas, much of the CONOPS is directly applicable to air cargo and air-taxi operators as well.

The largest cause of commercial aviation fatalities is poor situation awareness (SA) in low-visibility conditions. With the projected growth of the worldwide aircraft fleet, fatal aviation accidents are projected to increase proportionately unless the industry is made safer. SVS is expected to provide substantial safety benefits in both normal and low visibility conditions, which should dramatically assist in meeting the President’s 1997 national aviation safety goal of reducing the fatal aircraft accident rate 80% in 10 years.

In addition, SVS will provide operational benefits to air carriers that will lead to significant economic incentives. Interest in potential SVS operational benefits is steadily increasing with several commercial display products currently available.

<p>The CaB SVS mission is to enhance safety and enable consistent gate-to-gate aircraft operations in normal and low visibility conditions.</p>
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## Background

There are many stakeholders in the development of a CaB SVS CONOPS including: NASA, DoD, FAA, NATCA, NIMA, NGS, CaB pilots and airlines, aircraft and avionics manufacturers, airports, and academic institutions. The unique perspective of each group or organization is required for the development of a successful SVS CONOPS and an attempt was made to include their comments where possible in this document.

The current maturity level of enabling technologies and SVS research is the result of numerous research and development advances. These advances fall into the general categories of computing, flight deck display technology, precision navigation, mapping, and geodesy. Each of these advances has contributed to enhancing flight crew SA in low visibility conditions. CaB SVS research and development is aiming to further increase SA and pilot performance by integrating these technologies and flight procedures.

The following figure illustrates the present maturity of SVS research. Shown is a state-of-the-art display with symbology providing precision navigation information integrated with a photo-realistic terrain and object database. Using this SVS display, test pilots flew manual approaches to touchdown in November 1999.



**NASA Langley SVS Depiction of Approach to Asheville, NC**

### **CaB SVS Objective – Creating a Virtual Visual Environment**

The ability to conduct safe and efficient CaB flight operations in today’s environment is dependent upon a number of factors. Among these, adequate visibility is the most critical component. As weather and visibility deteriorate, it is increasingly difficult to conduct flight operations in the same manner and at the same rate as in VMC. SVS technology development is aimed squarely at solving this issue. In addition, SVS technology could provide information well beyond what the pilot is able to see even on a clear day. The operational concept behind SVS seeks to increase the safety and efficiency of both VMC and IMC operations by producing a *virtual visual environment*. This all but eliminates reduced actual visibility as a significant factor in flight operations, and enhances what the pilot can see in the best of visibility conditions.

Specifically, the SVS design needs to support minimums as low as Category IIIb in a variety of operational environments. Such a system will allow greater flexibility to taxi, depart, and arrive in Category IIIb or better conditions while using Type I or non-ILS equipped airports and runways. This is a significant challenge since the system must have performance, reliability, safety, and integrity that functionally equate to today’s CAT IIIb systems. The virtual visual environment is described in terms of its components and the operational flight phases it supports.

## **SVS Components**

The SVS virtual visual environment is composed of three components: an enhanced intuitive view of the flight environment, hazard and obstacle detection and display, and precision navigation guidance.

*Enhanced Intuitive View:* SVS will provide a picture of the environment in which the aircraft is operating. It is intuitive because it will replicate what the pilot would see out of the window in day VMC. This intuitive view is largely derived from terrain database background images with multi-system information superimposed upon, or integrated into them. SVS will incorporate the primary flight information currently available in modern CaB aircraft. That information is comprised of tactical information typically found on a primary flight display as well as strategic information currently found on navigation displays. It will include aircraft state data such as altitude, indicated airspeed, ground speed, true airspeed, vertical speed, velocity vector, and location with respect to navigation fixes. This component will also incorporate enhancements to the view, which highlight important features relevant to safe and efficient operation of the flight in any visibility.

*Hazard/Obstacle Detection & Display:* Hazard and obstacle avoidance is a prerequisite for safe operations in all flight phases. SVS would serve to display terrain and obstacles that present hazards to the aircraft as well as provide warning and avoidance alerting. Some suggested display concepts depict terrain (land, vegetation), ground obstacles (aircraft, towers, vehicles, construction, wildlife) and air obstacles (traffic, wildlife), atmospheric phenomena (weather, turbulence, wind shear, icing, wake vortices), restricted airspace, and politically (noise) sensitive areas.

*Precision Navigation Guidance:* Using potential SVS virtual renditions of taxi maps, tunnel/pathway guidance and navigation cues, pilots can accurately view own-ship location, and rapidly correlate position to terrain and other prominent features. This component enables the pilot to access and monitor path-following accuracy and is an important component in achieving low RNP/RNAV approach minimums, supporting curved approaches, and following noise abatement procedures.

## **SVS use by Flight Phase**

SVS will support operations during all phases of flight — ground operations, departure, en route, and arrival.

*Ground Operations Between Gate and Runway:* In order to realize higher flight operation rates potentially afforded by SVS technology, aircraft must first be able to maneuver safely and expeditiously between the runway and gate areas. SVS will enable the safety and efficiency associated with clear daylight operation to be realized at night and in low-visibility conditions. This includes the elimination of runway incursions at night and in conditions of reduced visibility as well as in VMC.

Departure Operations: SVS will enhance safety by providing the pilot with an extended visual recognition range and alerting independent of visual obscurations. The capability to maintain directional control and reject takeoffs is enabled through information presented with the SVS display. SVS provides a pictorial view of an aircraft's environment including the runway edges and centerline, terrain, and obstacles. Additionally, ground and airborne traffic are visible.

En Route Operations: SVS will support aircrews in their monitoring of flight performance and avoidance of hazards en route, as well as support their transition into the descent/approach phase. This is especially true for low-level en route operations. Various display options could also be used to safely rehearse an approach during the en route phase of flight.

Arrival and Approach Operations: Approach operations have requirements that impose restrictions on the arrival to an airport. SVS will enable more flexible approaches to be flown, e.g., RNAV/RNP procedures. SVS provides the opportunity for in-trail and lateral spacing to be transferred from ATC to the aircrew regardless of visibility. Any terrain or obstacles that would impinge upon the intended approach, as well as runway traffic and other obstacles would be visible.

## **Benefits and Recommendations**

Current technology allows aircrews to perform all-visibility en route operations as well as low visibility approaches and landings to appropriately equipped runways. SVS will further increase aircrew SA and performance by integrating existing and new technologies and flight procedures into a *virtual visual environment* which expands safety and operational benefits in CaB ground operations, departure, en route, and arrival/approach. The key safety benefits for applying SVS are preventing CFIT and RIs and the key areas of operational benefit are supporting low-visibility ground operations, departures, and approaches. SVS and the virtual visual environment are well suited to provide both safety and operational benefits in these phases of flight.

Therefore, the CaB industry should pursue development of SVS technology to help overcome these operational limitations in both normal and terrain challenged airports and in visibility ranging from VMC down to IFR CAT IIIb. Government agencies should provide R&D assistance and the required communications, navigation, and surveillance (CNS) and database infrastructure for SVS to work to its potential. SVS could also have profound regulatory implications. In fact, the difference between seeing another aircraft in VMC and “seeing” that same aircraft with SVS not only presents challenges to certification, but might lead to an entirely new “electronic flight rules” or EFR world. As a result, in-depth discussions between researchers, the FAA, and any other agencies involved in certification should begin immediately. This approach will ensure that SVS will enhance safety and enable consistent gate-to-gate aircraft operations.

## 1 Introduction

Following several high-visibility commercial aircraft accidents, a White House Commission was established to study matters involving aviation safety and security. In response to this Commission's recommendations, the President set a national goal in February 1997 to reduce the aviation fatal accident rate by 80% within ten years. To help meet this goal the National Aeronautics and Space Administration (NASA) formed the Aviation Safety Program (AvSP).

With the expected growth of the worldwide aircraft fleet, the number of aviation accidents is projected to increase unless air travel is made safer and the accident rate is reduced.\* The largest cause of commercial aviation fatalities is poor situation awareness (SA) in low visibility conditions (night or poor weather). Low visibility forces pilots to become the integrators of disparate forms of data and information in order to fly their aircraft. Accidents and incidents caused by low visibility include controlled flight into terrain (CFIT), runway incursion (RI), approach and landing errors, and those due to flight path navigation errors. In addition, poor visibility also hampers overall operational effectiveness and creates costly air transportation system delays.

The Synthetic Vision Systems (SVS) Project is a 5-year effort to develop technologies, applications, and procedures that improve both the safety and effectiveness of civil aircraft operations.† Specifically, the goal of this work is to eliminate low visibility as a causal factor in civil aircraft accidents, and to replicate the benefits of flight operations in day visual meteorological conditions (VMC), regardless of the actual visibility.

The current climate of the commercial air transportation industry has also driven a demand for more flexible operations in low visibility conditions. Air traffic controllers, airlines, and pilots are continually voicing the need for improved operational flexibility and situation awareness through better information integration, intuitive displays, and decision aids. The general desire has been to reduce air travel delays and the associated costs caused by operating in the inflexible, rule-based environment currently required in low visibility conditions. As attractive as safety enhancements might be, the economic nature of the airline industry requires safety benefits to be coupled with increased operational capabilities. This will help ensure industry participation in the development, certification, and implementation phases of the project.

This document describes an initial concept of operations (CONOPS) for commercial and business aircraft (CaB) SVS. It is a "living document," which will be modified as the CaB SVS CONOPS is refined. It is intended to provide a continued focus for CaB SVS research, development, and implementation and to describe how air carriers might use these technologies. A follow-on requirements document will provide further details on SVS applications. In addition, a separate NASA effort is in progress to address certification issues.

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\* Aviation Safety Investment Strategy Team study of NTSB statistics, 1997.

† AvSP Preliminary Program Assessment, Jan 2000 and the 3 Pillar Goal Study, Nov 1999 which provided modeling and simulation estimations of safety benefits.

SVS will support safe aircraft operations gate-to-gate (taxi, departure, en route, arrival/missed approach, landing, taxi, parking). Within the operational flight phases, several sub-concepts or applications are introduced in this document and set the stage for further SVS concept exploration. Although the technology associated with SVS is applicable in all weather conditions, operations in Category IIIc conditions (zero ceiling and runway visibility) are not being addressed at this time. Fortunately, the weather minimums that would require CAT IIIc use are rarely encountered. Consequently, the focus of this CONOPS is to support SVS development of a *virtual visual environment* to allow VMC-like operations in normal and low visibility (Category IIIb or better visibility conditions – see Appendix A for visibility category definitions).

The CaB SVS mission is to enhance safety and enable consistent gate-to-gate aircraft operations in normal and low visibility conditions.

## 1.1 Acronyms and Abbreviations

3D	three-dimensional
4D	four-dimensional (3D plus time)
ADS-B	Automatic Dependent Surveillance - Broadcast
AH	alert height
AILS	Airborne Information for Lateral Spacing
ALPA	Air Line Pilots Association
AMASS	Airport Movement Area Safety System
ASDE	Airport Surface Detection Equipment
ATA	Air Transport Association of America
ATC	air traffic control
ATL	The William B. Hartsfield Atlanta International Airport
ATM	air traffic management
AVOSS	Aircraft Vortex Spacing System
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
BLH	analysis technology: baseline + HUD
CaB	commercial and business-jet
CAT I	Category I
CAT II	Category II
CAT III	Category III
CDTI	Cockpit Display of Traffic Information
CFIT	controlled flight into terrain
CFR	crash, fire, and rescue
CNS	communication, navigation, and surveillance
CONOPS	concept of operations
CONUS	Continental United States
COTS	commercial off-the-shelf
CPDLC	Controller-Pilot Datalink Communications
CRM	crew resource management
CRT	cathode ray tube
DCA	Ronald Reagan Washington National Airport
DEVS	Driver's Enhanced Vision System
DFW	Dallas-Fort Worth International Airport
DGPS	Differential Global Positioning System
DH	decision height
DoD	Department of Defense
DP	departure procedure
DROM	Dynamic Runway Occupancy Measurement
DTW	Detroit Metropolitan Wayne County Airport
EADI	electronic attitude director indicator
EFIS	electronic flight instrument system
EGPWS	enhanced ground proximity warning system
EUROCAE	European Organization for Civil Aviation Equipment
EVS	enhanced vision system

EWR	Newark International Airport
FAA	Federal Aviation Administration
FAR	Federal Aviation Regulation(s)
FLIP	Flight Information Publication
FLIR	forward-looking infrared
FMS	flight management system
ft	feet
FY	fiscal year
GA	general aviation
GMTI	ground moving target indicator
GPS	Global Positioning System
HDD	head-down display
HMD	head-mounted display
HSALT	Hold Short Advisory Landing Technology
HSCT	High Speed Civil Transport
HUD	head-up display
ICAO	International Civil Aeronautics Organization
IFR	instrument flight rules
ILS	instrument landing system
IMC	instrument meteorological conditions
INS	inertial navigation system
IRS	inertial reference system
JFK	John F. Kennedy International Airport
LAAS	Local Area Augmentation System
LAHSO	Land and Hold Short Operations
LaRC	Langley Research Center
LAX	Los Angeles International Airport
LCD	liquid crystal display
LMI	Logistics Management Institute
LNAV	lateral navigation
LVLASO	Low Visibility Landing and Surface Operations
MIT	miles-in-trail
MMWR	millimeter wave radar
MSP	Minneapolis-St. Paul International (Wold-Chamberlain) Airport
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
ND	navigation display
NGS	National Geodetic Survey
NIMA	National Imagery and Mapping Agency
NOTAM	Notice to Airmen
ORD	Chicago O'Hare International Airport
PF	pilot flying
PFD	primary flight display
PNF	pilot not flying
RADAR	radio detection and ranging
RI	runway incursion

RIPS	Runway Incursion Prevention System
RIRP	Runway Incursion Reduction Program
RNAV	area navigation
RNP	required navigation performance
ROT	runway occupancy time
ROTO	Roll-Out and Turn-Off
RS	reduced separation
RTCA	RTCA, Inc.
RTO	rejected takeoff
RVR	runway visual range
SA	situation awareness
SAR	synthetic aperture radar
SEA	Seattle-Tacoma International Airport
SFO	San Francisco International Airport
SID	Standard Instrument Departure (note: Current phraseology is DP, departure procedure)
SMGCS	Surface Movement Guidance and Control System
SRTM	Shuttle Radar Topography Mission
SV1 to 3	analysis technologies: Synthetic Vision
SVS	Synthetic Vision System
TAWS	Terrain Awareness and Warning System
TCAS	Traffic Alert and Collision Avoidance System
TIS-B	Traffic Information Systems - Broadcast
TOC	Top of Climb
TOD	Top of Descent
T-NASA	Taxiway Navigation and Situational Awareness
TSRV	Transport Systems Research Vehicle
UAV	unmanned aerial vehicle
USGS	United States Geodetic Survey
V <sub>1</sub>	critical engine failure recognition speed
V <sub>2</sub>	takeoff safety speed
V <sub>R</sub>	rotation speed
VASI	visual approach slope indicator
VFR	visual flight rules
VMC	visual meteorological conditions
VNAV	vertical navigation
VSAD	vertical situation awareness display
WAAS	Wide Area Augmentation System

## 1.2 SVS Development Background

Several research and development initiatives have provided enabling technologies and led to the current state of SVS research. These efforts have developed various components that enhance flight crew situation awareness in low visibility conditions. Commercial interest in the operational benefits derived from enhancing pilot SA and performance in low visibility is steadily increasing with several commercial display products available. Several key initiatives in recent years include:

- Millimeter Wave Radar (MMWR) and Forward-Looking Infrared (FLIR) flight research
- Head-Up Display (HUD) development
- Head-Mounted Display (HMD) development
- Tunnel/Highway-in-the-sky development
- Development of Terrain Following Radar, Synthetic Aperture Radar (SAR), and Ground Moving Target Indicator (GMTI)
- Mapping, Charting & Geodesy (MC&G) Improvements – especially Global Positioning System (GPS) technology development and precision geo-location
- Datalinks: Controller-Pilot Datalink Communications (CPDLC), Automatic Dependent Surveillance – Broadcast (ADS-B)
- Cockpit Display of Traffic Information (CDTI)
- Development of an external-vision system for the High Speed Civil Transport (HSCT) which was designed to have no forward windows
- Increasingly Accurate Worldwide Terrain Database – Shuttle Radar Topography Mission (SRTM)
- Depiction of Severe Weather from off- and on-board sensors
- Computing Technology (especially processing speed and memory) growth
- Display Technology (especially liquid crystal displays) growth
- Commercial Off-The-Shelf (COTS) graphics processors (boards and chips) improvement (largely driven by video gaming/entertainment industry)
- Solid state GPS/INS (Inertial Navigation System) development
- Published standards for avionics computing resources (RTCA DO-255, July 2000)
- Wake vortex prediction studies

Figure 1.1 illustrates the present maturity of SVS display research. Shown is a state-of-the-art display with symbology providing precision navigation information integrated

with a photo-realistic terrain and object database. Using this SVS display, test pilots for a NASA study flew manual approaches to touchdown in November 1999.



**Figure 1.1 NASA Langley SVS Depiction of Approach to Asheville, NC**

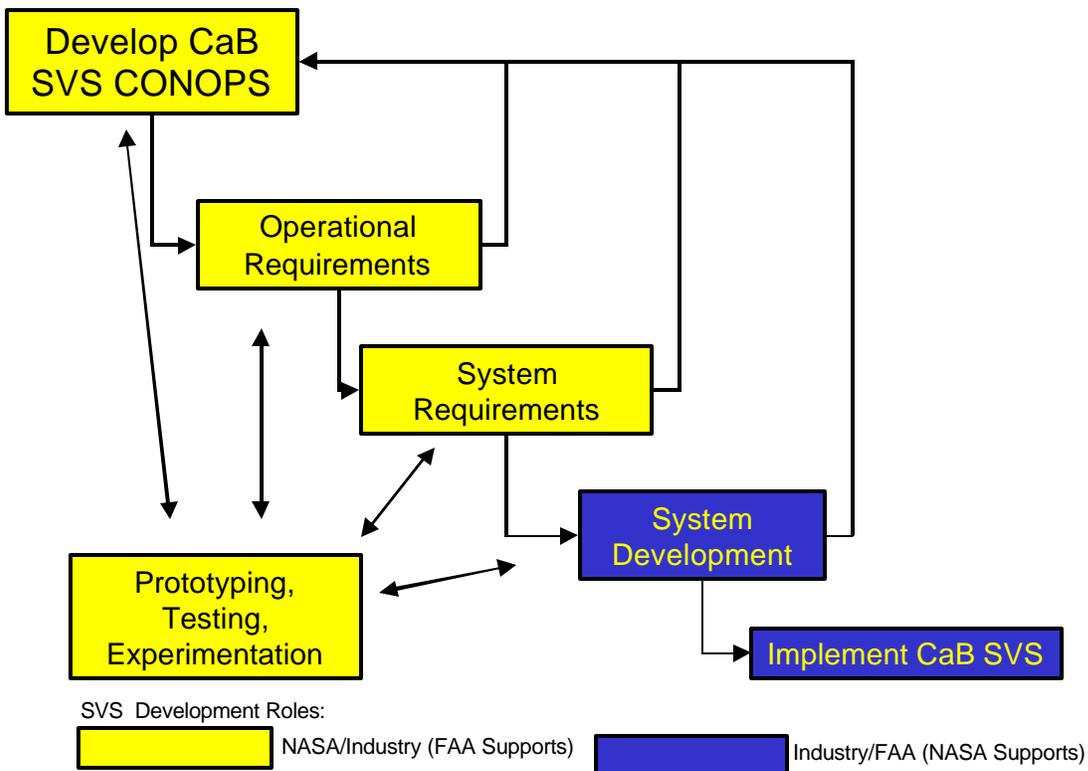
### 1.3 CaB SVS Development

While there exists a significant technological capability to support low visibility operations today, CaB SVS research and development is aiming to further increase SA and pilot performance by integrating these technologies and flight procedures. The SVS concepts and displays as currently conceived will allow for presentation of the necessary information with appropriate realism to be equivalent to day VMC, regardless of the outside visibility. The CaB SVS development effort is intended to eliminate visibility-induced errors to maximize safety and operational benefits.

In this way, SVS will attempt to realize and demonstrate the potential safety and operational benefits for CaB by improving SA with respect to terrain, traffic, weather hazards, and tactical flight path management. CFIT accident reduction efforts will target the operational environment for all phases of flight, including approach, landing, and missed approaches. Runway incursion reduction efforts will target surface surveillance, GPS-based navigation, and CDTI.

SVS will also have to be developed for a mixed fleet of CaB aircraft. Approximately one-third of today's air carrier fleet is equipped with electronic displays of various sophistication and capabilities. For these aircraft, SVS information could be effectively imparted to the crew head-down on existing form factor A-, B-, or D-size displays in a retrofit application. The remaining two-thirds of the current air carrier fleet, equipped with electromechanical instruments only, have no inherent means of displaying synthetic vision scenes. However, the installation of HUDs among air carriers is gaining momentum and tactical SVS information could be displayed on the space provided by raster-style HUDs. Future aircraft, with potentially larger, more sophisticated displays, could incorporate SVS technology during the design stage.

The SVS development process illustrated in Figure 1.2 includes the CaB SVS CONOPS in support of CaB aircraft operations. Following the development of the CaB SVS CONOPS, requirements will be derived to provide a focus for system development. The CaB SVS development will be led by NASA Langley Research Center (LaRC) in partnership with the FAA and private industry. Candidate prototypes will be evaluated through testing and experimentation. The concepts are iteratively refined, implemented, and evaluated until a sufficient maturity level is realized for FAA certification and industry implementation of a commercial product. While the CONOPS is depicted in Figure 1.2 as the first stage, improvements to the concept will be incorporated through the other development cycle stages.



**Figure 1.2 CaB SVS Development Process**

## 1.4 CaB SVS Project Objectives

The general objective of the CaB SVS Element is to develop technology, candidate components, and procedures that replicate and augment the safety and operational benefits of flight operations in clear-day VMC. This concept includes cockpit display of real-time information integrated with stored data to support operational flight procedures. SVS will also provide the operational flexibility to taxi, depart, and arrive even at non-ILS equipped runways in CAT IIIb visibility conditions. For departure and ground operations, an SVS goal is to enable operations with a Runway Visual Range (RVR) as low as 300 feet. (See Appendix A for visibility category definitions.) Head-up departures in 300 ft RVR are allowed today by coupling to a CAT II/III localizer for centerline guidance. Many aircraft are configured to do this. The desire to use SVS head-down provides a retrofit option for aircraft not equipped with HUDs.

The following objectives advance the development of SVS technologies, provide supporting empirical evidence for eliminating the targeted accident categories, and expedite the implementation readiness level for SVS technology:

- Develop and demonstrate affordable, certifiable, display configurations (including retrofit) to provide intuitive terrain and obstacle information suitable to augment the outside view for commercial air carriers and business aircraft.
- Develop and demonstrate synthetic vision display concepts, which provide enhanced terrain awareness for proactive avoidance of CFIT precursors.
- Develop and demonstrate enabling technology to provide intuitive guidance cues to allow precision approaches and landings using terrain, obstacle, and airport databases and GPS-derived navigation.
- Develop and demonstrate enabling technology to enhance airport surface awareness, including displays of surface routing information, other traffic information, and RI alerts obtained from surface surveillance systems and automated incursion-alerting systems.
- Demonstrate through high fidelity simulation how proposed display concepts could reduce the rates of CFIT, RI, and other visibility-induced accidents.
- Identify the operational benefits of synthetic vision systems that will motivate the commercial aviation industry to invest in SVS development, acquisition, and implementation while improving aviation safety.
- Support the integration of air traffic information, hazardous weather information, and on-board self-separation capabilities in SVS.
- Support the implementation of developed technologies through systems engineering, integration, and certification planning and demonstrate conformance

of technologies with the evolving Communication, Navigation, and Surveillance (CNS) environment and National Airspace System (NAS).

- Support the development of SVS display, database, and alerting standards by providing user and system requirements.\* These requirements will allow for incremental system growth by SVS developers.

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\* Displays should be consistent with existing standards, SAE "Flight Deck Alerting System (FAS)," SAE ARP-4102/4, July 1998.

## 2 SVS Operational Concept – *Creating a Virtual Visual Environment*

The ability to conduct CaB flight operations in today's environment is dependent upon a number of factors. Among these, reduced visibility is a significant concern. As weather and visibility deteriorate, it is increasingly difficult to conduct flight operations in the same manner and at the same rate as in VMC. While today's technology provides solutions to many of these problems caused by low visibility, the potential exists to also provide information well beyond what the pilot is able to see even on a clear day. The operational concept behind SVS is to create this *virtual visual environment* that all but eliminates reduced actual visibility as a significant factor in flight operations and enhances what the pilot can see even in the best of visibility conditions. The virtual visual environment is described in terms of its components (section 2.1), and the operational flight phases it supports (section 2.2).

### 2.1 SVS Components

The SVS virtual visual environment is composed of three components: an enhanced intuitive view of the flight environment, hazard and obstacle detection and display, and precision navigation guidance.

*Enhanced Intuitive View*: SVS will provide a picture of the environment in which the aircraft is operating. It is intuitive because it will replicate what the pilot would see out the window in day VMC. This intuitive view is derived from terrain database background images with multi-system information superimposed or integrated into them. This information is comprised of tactical information typically found on a primary flight display as well as strategic information currently found on navigation displays. It will include aircraft state data such as altitude, indicated airspeed, ground speed, true airspeed, vertical speed, velocity vector, and location with respect to navigation fixes. Additional information like tunnel/pathway guidance would also be provided. This component will also incorporate enhancements to the view that emphasize important features relevant to safe and efficient operation of the flight in any visibility.

Since cluttered displays are undesirable, pilots will be given the ability to choose certain features so the system reflects immediate priorities. Display flexibility will be balanced with simplicity. For example, a default or "home" display selection that would be immediately available could be a desirable feature.

The required redundancy and level of reliability of SVS is a function of the criticality of the operations being performed. Reversionary modes that provide graceful degradation along with various levels of redundancy and backup will be included. Subsystem redundancies and crosschecking will be required to ensure the integrity of flight critical information. In addition, fail passive and fail operational capabilities will be an integral part of the system. It is imperative that no single failure be allowed to cause a flight safety hazard. The enhanced intuitive view must also be designed to minimize nuisance alerts, effects of spurious data, and other anomalies.

Independent integrity monitors for both surveillance and navigational functions would likely be required to meet certification and safety requirements. SVS will rely on sensors like modified weather radar and/or high quality radio altimeters to provide real-time monitoring for the databases.\* Such monitoring could include air-to-air traffic surveillance, runway incursion monitoring, and navigation database confirmation.

While it might be tempting to describe SVS simply as an integration of information and interfaces currently available in modern glass flight decks, in reality, it will greatly extend these conventional displays to be far more intuitive. In addition, it will include graphical illustrations of the flight environment as well as information from non-critical and flight critical systems.

*Hazard/Obstacle Detection & Display:* Hazard and obstacle avoidance are prerequisites for safe operations in all flight phases. SVS would serve to display and appropriately highlight terrain and obstacles that present hazards to the aircraft during all phases of operation. Some suggested areas for display are terrain (land, vegetation), ground obstacles (aircraft, towers, vehicles, construction, wildlife), airborne obstacles (traffic, wildlife), atmospheric phenomena (weather, turbulence, wind shear, icing, wake vortices), restricted airspace, and politically (noise) sensitive areas.

Using on-board enhanced vision system (EVS) data, there are many possible implementations. Enhanced vision refers to data and images acquired from sensors such as video cameras, conventional radar, enhanced weather radar, SAR, MMWR, or FLIR. Sensor images can be overlaid, processed, integrated, or fused to augment on-board displays and assess database integrity. Since not all sensor images are intuitive, salient features or hazards would be extracted from the sensor data and highlighted or depicted as symbols or icons.

Broader versions of SVS could include EVS in both head-down and head-up applications. In addition, SVS integrated with Terrain Awareness and Warning System (TAWS) will provide additional safety benefits. Coupling a database with sensor information to depict static and dynamic hazards would insure that SVS provides an accurate representation of the real world. With this kind of dynamic representation, situations requiring immediate evasive action would be minimized.

*Precision Navigation Guidance:* Using SVS virtual displays such as taxi maps, tunnel/pathway guidance and navigation cues, pilots can accurately view own-ship location, and rapidly correlate their position to terrain and other prominent features. This component enables the pilot to monitor navigation precision and is an important component in lowering RNP/RNAV approach minimums, as well as supporting curved approaches and following noise abatement procedures. Self-spacing algorithms can also be incorporated into SVS displays, leading to a variety of operational benefits during both ground and flight operations.

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\* \* EUROCAE Working Group 44/Joint Special Committee RTCA 193 is developing database requirements for the developing, implementing, and updating of the database(s) that are going to be used in SVS.

SVS will be referenced to GPS or DGPS, depending on available technology and application. If GPS becomes unreliable or is not available, SVS equipped aircraft will utilize other forms of position updating or revert to a reversionary mode of operation. Installation of SVS on older aircraft will require GPS equipment similar to that installed in current-generation aircraft.

Database integrity will be an area of significant focus. The terrain, airport layout, and obstacle data must be of sufficient integrity to support precision navigation. By combining sensor and database information, the accuracy and integrity required to support operations down to Category IIIb minima for approach and 300 ft RVR will likely be feasible.

As a minimum, a precision navigational system provides the ability to accurately navigate to a 3D location. While the focus for this study is to create precision 3D navigation, adding a time requirement for 4D navigation might have merit in certain operational environments.

## 2.2 SVS Use – By Flight Phase

SVS will support operations during all phases of flight. This section describes applications that are of particular interest and discusses their operational procedures. Appendix B contains summarized descriptions of many potential SVS applications that were recorded at the February 2000, CaB SVS CONOPS Workshop. A candidate set of applications, selected for near-term SVS development and implementation, will be described in more detail in a follow-on requirements document.

### 2.2.1 Ground Operations Between Gate and Runway

Previous research has explored technology intended to provide visual cues to the pilot during periods of reduced visibility or at night. It is recognized that current-generation commercial aircraft are capable of landing with visibility as low as 150 feet and taking off with visibility as low as 600 feet.

Runway visual range is measured adjacent to a given runway at three points: touchdown, mid-field and roll out. Table 2.1\* reflects the impact on operations that can be expected with decreasing RVRs.

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\* Source: Richard B. Gifford, Airline Captain, Retired

**Table 2.1 Operational Implications of Runway Visibility Ranges**

RVR (feet)	DESCRIPTION
5000	Airport and aircraft IMC operations are normal both daylight and night.
2400	Taxi speed may be reduced somewhat below the normal straight-ahead taxi speed of 20-25 knots.* Areas of reduced visibility may be expected and taxi speed adjusted accordingly, but taxi time to the gate is not delayed appreciably.
1200	Taxi speed may be reduced to 10-15 knots. Areas of very low visibility may exist. The pilot may have trouble locating the gate, especially at an unfamiliar airport. Taxi times to and from the runway are increased slightly.
600	Visually acquiring ground vehicles is difficult. Just as when driving on the highway, some drivers operate their service vehicles at a speed too fast for the conditions.
300	Taxi speed is reduced to about 10 knots (the approximate speed used on the initial turn toward the gate) to accommodate the potential of zero visibility. Additional guidance in the form of green imbedded taxi lights or a "Follow Me" vehicle is very desirable. On one occasion at Frankfurt where the landing was accomplished with reported visibility of 125 Meters, over 30 minutes additional time was required to taxi to the gate. Areas of near-zero visibility were encountered.
150	Taxi speed is reduced to 5 knots. Painted surface markings are of marginal value due to lack of contrast. Cockpit cut-off angle becomes a significant factor in maintaining centerline control. Signs adjacent to taxiway may be difficult to see. Taxi times are substantially increased.
0	Nothing is visible forward through the windshield. The edge of the runway or taxiway is visible only by looking down from the side window of the cockpit. Safe movement of the aircraft is no longer possible. If the aircraft must be moved for safety reasons (for example, to clear a runway), taxi speed is that of a walk (2 knots).

Because ground operations are so complex, (see Appendix C), low visibility can have a devastating effect on their efficiency and safety. Therefore, ground operation in low visibility is one of the areas where SVS can be of greatest benefit.

#### 2.2.1.1 SVS Enhancements to Ground Operations

In order to maintain higher rates of runway operations afforded by SVS technology in other flight phases, aircraft must be able to maneuver safely and expeditiously between the runway and gate areas. SVS will enable the safety and efficiency normally associated with day VMC operations to be realized at night and in low-visibility. ATC provides clearances for surface operations including assigned taxiways, critical reporting points, and coordination with other aircraft. Clearances may be provided through voice and/or datalink. SVS will provide the pilot with this same clearance information. The system will display the cleared path to the runway, as well as turn cues when intersections are approaching. This will help to prevent airport gridlock, eliminate taxi errors or excursions from the paved surface, and avoid obstacles while taxiing at normal speeds in low visibility conditions. Optimal surface operations can be achieved by providing cues

\* Actual speeds may differ depending on airline policy and pilot discretion.

and guidance in an SVS display that complement or replace the visual cues provided by standard low-visibility airport features such as signs, lighting, and markings. Appropriate, familiar, and intuitive displays of path guidance and obstacles, whether stationary or moving, man-made or natural, will be presented in such a way as to prevent RIs and any other deviation from safe operations. Such a system will not only provide operations equivalent to those exhibited in clear daylight visibility, but could increase crew confidence, alleviate taxi clearance misunderstandings, and greatly reduce confusion in the cockpit especially during night operations at airports with complex layouts.

To avoid accidents and RIs, ground operations could also depend on sensor-based detection of obstacles, vehicles or traffic. Some applications will also require data exchange between aircraft.

Goals of SVS for ground operations are:

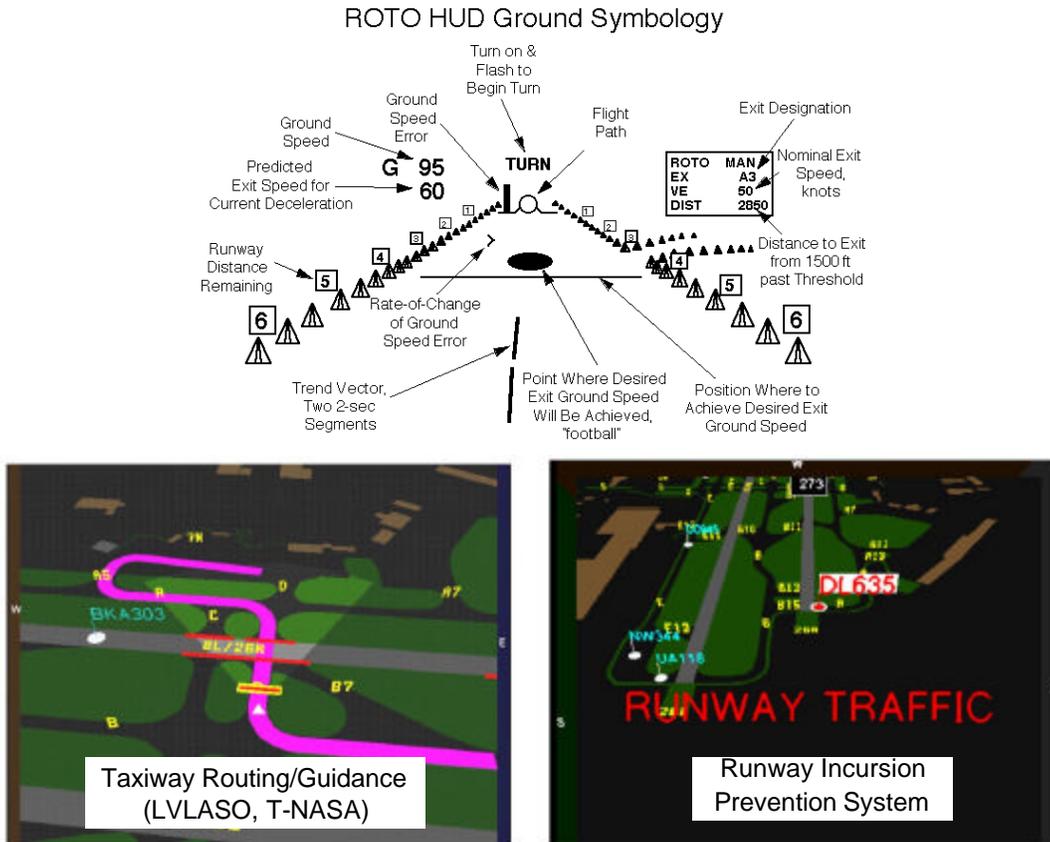
- Providing a means of operating in the ground environment in conditions of reduced visibility (300 ft RVR) with levels of safety and efficiency equivalent to VMC — This would include development of system performance standards and hazard mitigation technologies for plausible system failures such as loss of guidance signals and on-board equipment failures.
- Eliminating RIs in all visibility conditions

#### 2.2.1.2 Associated Technologies and Research

Several established and emerging research efforts address low-visibility surface operations and are important components of the SVS concept. SVS will integrate information from these technologies and will incorporate lessons learned from other research projects. The Low Visibility Landing and Surface Operations (LVLASO) project at the NASA was designed to develop and demonstrate technologies that will safely enable clear-weather capacities on the surface in IMC. A Rollout and Turn-Off (ROTO) guidance and control system was designed to allow pilots to perform a safe, expeditious, high-speed rollout and turn-off after landing regardless of runway conditions and visibility. A Taxiway Navigation and Situational Awareness (T-NASA) system was designed to improve SA in the flight deck such that taxi operations can be performed safely and efficiently regardless of visibility, time of day, airport complexity, or pilot unfamiliarity with the airport. A Dynamic Runway Occupancy Measurement (DROM) system was designed to capture runway occupancy times (ROTs) in real-time. A database of these times is maintained for use by controllers and pilots to aid in optimizing inter-arrival spacing.

The LaRC Runway Incursion Prevention System (RIPS) consists of tactical and strategic displays in the form of airport surface depictions enhanced with aircraft and surface vehicle position symbology. RIPS also provides SA and timely warning of potential conflicts. Supporting technology includes datalink, position determination system, surveillance system, and controller interface.

Figure 2.1 includes examples of ground operations displays used in low-visibility research at NASA (Ref 1). The symbology used in the ROTO head-up display is illustrated in the upper portion of the figure. A taxiway routing and guidance display, used in earlier LVLASO and T-NASA research, and the RIPS display are shown in the lower portion.



**Figure 2.1 Notional Ground Operation Displays and Features**

Technologies developed by FAA and industry are foundational to a successful implementation of SVS, especially in ground operations. These activities are demonstrating operational feasibility, generating and validating requirements, and assessing candidate supporting technologies (e.g. DGPS, CPDLC, ADS-B, Traffic Information Systems-Broadcast (TIS-B), and ATC color displays). A holistic systems approach requires compliance with the Safe Flight 21, Free Flight, CNS/ATM, and SMGCS concepts. The FAA's Office of System Architecture and Investment Analysis provides documentation of future programs for the NAS that include timelines, cost, and milestone accomplishments. Examples (and FY target dates) are listed in table 2.2.

**Table 2.2 NAS Architecture Programs Candidates for Integration Into SVS**

<b>Implementation Year</b>	<b>Program</b>
2002	<ul style="list-style-type: none"> <li>• GPS/Wide Area Augmentation System or WAAS</li> <li>• Cockpit Display of Traffic Information or CDTI</li> <li>• Airport Movement Area Safety System or AMASS</li> <li>• Controller-Pilot Datalink Communications or CPDLC</li> <li>• Traffic Information Systems-Broadcast or TIS-B</li> </ul>
2005	Automatic Dependent Surveillance-Broadcast or ADS-B
2007	GPS/Local Area Augmentation System or LAAS

Program descriptions can be found in the FAA's NAS Architecture, Version 4 document (Reference 2). The programs listed in table 2.2 are candidates for integration into SVS.

### 2.2.1.3 Candidate Ground Operation Display Features

As currently envisioned, SVS will incorporate these display features for ground operations:

- DGPS navigation capability for precision positioning — This includes current location and a predictor of the taxi path, intuitively showing the proximity to taxiway edges and other obstacles/traffic.
- A high-precision graphical depiction of the airport ramp, taxiways, runways, and significant infrastructure that correlates with the outside view
- Hazards and obstacles of significance: construction, aircraft, wildlife, ground support vehicles and personnel — This includes alerting and resolution guidance to prevent taxi errors and RIs.
- Intuitive depiction of ATC taxi clearance
- A guidance display that predicts nose and main gear location and trajectory to assist in taxiing
- Forward looking sensors, using FLIR, enhanced weather radar, or MMWR technology — The data from these sensors, not necessarily the raw images, would be the basis of the depiction of obstacle information not contained in the geo-database on the forward-looking display and provide database integrity monitoring.
- A declutter capability for the SVS display — This is required to effectively manage the information available versus the information of priority to the pilot's current task.

## 2.2.2 Departure

The departure phase of flight is defined to begin when the aircraft's brakes are released, and power is applied with the intent to take off. Departure continues until the aircraft transitions to its en route portion of flight at the Top of Climb (TOC).

The concept for how SVS will support departure operations in IMC, is drawn from how those departures are conducted in VMC operations. For an aircraft to depart under today's operations the following conditions must exist:

1. The pilot must be able to see the runway location; as a minimum, the runway edges and centerline must be visible.
2. The pilot must be able to guide the aircraft accurately along the runway during the run up to takeoff speed.
3. The pilots must have access to the information normally provided by flight instruments to support takeoff operations. This includes airspeed for takeoff, and a presentation of  $V_1$ ,  $V_R$ , and  $V_2$ .

### 2.2.2.1 SVS Enhancements to Departure Operations

SVS will enable departures in reduced visibility by providing the flight deck with the capability to:

1. View the runway edges and centerline based on database information and accurate, reliable sensing of own-ship position. The pilots must be able to guide the aircraft accurately along the runway centerline while accelerating to takeoff speed. Pilots normally make takeoffs head-up, so depending on how the SVS forward-view is implemented, the head-down display (HDD) or HUD should provide this same runway display and centerline guidance capability. Parallel traffic should also be depicted.
2. Display sensor-based information that warns of obstacles on the runway that may pose a threat to the safety of a departure operation prior to takeoff. The sensors may include onboard instrumentation such as FLIR or other radar and data-linked information from equipment such as ASDE, ADS-B, or CPDLC.
3. Display enhanced guidance cues to enable the pilot to proceed on a safe departure route. This capability would apply to operations on parallel departure runways that may be more closely spaced than 2500 feet. The system should provide alerts to the pilot when there is inadequate navigation performance.

Before entering the active runway, the flight crew is required to visually check the approach to the runway and the runway itself for airborne and ground traffic and obstacles. SVS will enhance safety by extending the pilot's visual recognition range and

providing alerting independent of visual obscurations.\* In addition, since the decision to reject the takeoff becomes more dangerous as the aircraft accelerates, SVS will provide near real-time object and traffic detection, (preferably) before the takeoff roll has begun.

During takeoff, not only is it necessary for the pilot to maintain runway alignment, but aircraft engine instruments and performance must be monitored. In addition, most CaB operators incorporate an "eighty knot" check and verbally announce  $V_1$ ,  $V_R$ , and  $V_2$  by the pilot not flying (PNF), to confirm speeds the pilot flying (PF) sees on his/her airspeed indicator. As a result, SVS will depict runway edges and centerline to support proper alignment.

Once airborne, the flight path must be maintained within the airspace designated. The pilot may assume responsibility for separation from all other airborne traffic, including establishing a divergent flight path with aircraft departing on parallel paths<sup>†</sup>. To support this SVS will provide an intuitive view of relevant traffic and an allowable trajectory for the aircraft to fly, as well as any appropriate restrictions along the departure path.

Once airborne, the crew would maintain visual separation from parallel traffic using the same display. An SVS depiction of path and terrain will give the crew the added situation awareness important in certain terrain-affected departure operations.

If there is departure traffic from a parallel runway or from an aircraft executing a missed approach, SVS will display a clear and safe escape procedure if one aircraft deviates from its nominal path and threatens the other. This capability, along with a visual depiction of the traffic, is a requirement for pilots to accept responsibility for separation.

Redundancy will be designed into SVS. Automatic default to a back-up system would occur if self-checks of accuracy indicate inadequate performance within the system. Triple system redundancy may be necessary to provide the required dispatch reliability.

In departure operations, SVS will provide the capabilities necessary to allow parallel runways to continue to operate as independent runways or similarly capable parallel runways in VMC. Current restrictions and procedures for several departure environments are presented in Appendix D.

Separation requirements for departure operations in closely spaced parallel and intersecting runway environments may require technology similar to Airborne Information for Lateral Spacing (AILS, References 3 & 4) and paired-staggered operations to enhance safety (Reference 5). Those features will protect the flight from traffic hazards by providing alerting and other safety features. SVS requires surveillance information (e.g., Traffic Alert and Collision Avoidance System (TCAS), ADS-B, TIS-B) to be functional during departure operations.

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\* On-board sensors are subject to line-of-sight limitations, but through the networking of sensor information, line-of-sight limitations can be overcome and included dynamically into a database.

<sup>†</sup> Especially to maintain situation awareness of traffic on an adjacent runway if it is closer than 2500 feet laterally.

A desired consequence of using SVS displays for depiction of centerline guidance, traffic and obstacles is the reduction of visibility minima. SVS would enable the pilot to depart any runway, including those not equipped with centerline lights, in visibility as low as 300 ft. The justification behind this visibility selection comes from an operational benefit modeling analysis which determined 300 feet RVR to be the “breakthrough point” where operational/economic payoff increases sharply for an SVS capability (see Reference 5). The capability to maintain directional control and reject takeoffs is enabled through information presented with the SVS display. SVS provides a pictorial view of an aircraft’s environment. In particular, the runway outline and centerline, surrounding terrain, and known obstacles are depicted. Additionally, ground and airborne traffic and runway obstructions would be visible. SVS in that application would provide appropriate system accuracy, reliability, and redundancy to ensure safe operations similar to CAT II or CAT III operations at Type-II or Type-III facilities.

There are also operational implications for airports that have multiple runway departures. If departing aircraft were equipped with SVS, virtual visual departures on parallel runways could be possible in any visibility. When adjacent aircraft are both SVS equipped, air traffic controllers would be able to apply visual separation standards because the aircrew could maintain visual contact until they diverge. Visual separation procedures may similarly apply when a departing aircraft and an aircraft executing a missed approach are both SVS equipped.

#### 2.2.2.2 Using SVS to Prevent CFIT in Departure Operations

SVS will provide an intuitive, clear day view of the terrain along the path of the aircraft. SVS will include a prediction of the path of the aircraft relative to terrain or obstacles using current state information (e.g., velocity vector). It will present guidance information to maintain a safe path. SVS will show any terrain and obstacle threats and display the performance capabilities of the aircraft to aid the pilot in avoiding CFIT. This would be especially valuable in the event of loss of power on take-off at certain airports.

#### 2.2.2.3 Using SVS to Prevent RIs in Departure Operations

SVS will depict potential RI situations and provide cueing and alerting to prevent, warn of, and avoid RIs with other aircraft, ground support vehicles, ground crew and wildlife. Enhanced aircraft state and controls information (i.e., thrust setting, acceleration, thrust reversers, braking, etc.) could be datalinked to be used in algorithms for evaluating the threat of proximate traffic and provided to the aircrew as warnings or alerts when appropriate to aid in preventing RIs.

#### 2.2.2.4 Candidate Departure Display Features

SVS will incorporate those display features needed to make a safe departure. Features that are core to the synthetic vision concept, such as a perspective runway depiction and a display of terrain and fixed obstacles should be available initially. Additional features, like depiction of traffic information, depend functionally on the availability of enhanced surveillance data (ADS-B or TIS-B). Other features like the depiction of non-cooperative obstacles will be incorporated as their enabling technologies (e.g., enhanced weather

radar, FLIR, MMWR) mature. Below are candidate SVS display features for departure applications:

- The runway edges and centerline
- Weather hazards such as windshear, thunderstorms, turbulence, in the departure path
- Wake vortex hazards
- Obstacles on and adjacent to the runway: construction, aircraft, wildlife, ground support vehicles and personnel
- A flight path predictor, showing the proximity of terrain, obstacles, and traffic
- A guidance display of information for maintaining an intended path, including indications of runway remaining during takeoff
- An alerting capability that warns the pilot of prominent terrain — This may be similar to current TAWS capabilities, but should include more proactive or strategic protection. If alerting features are used, recovery procedures for dealing with alerts must be incorporated.
- A graphical depiction of the terrain, airport, and significant infrastructure, driven from a terrain database — This imagery would be shown in a forward-view HDD or HUD. Current PFD symbology, including path guidance, would be superimposed on the database images.
- CDTI — This would be a plan-view HDD of the flight path and relative location of traffic. Current ND symbology will be included in this display and integrated into the virtual visual forward-view.
- Forward-looking sensors, using FLIR, enhanced weather radar, or MMWR technology — The data from these sensors, not necessarily the raw images, would be the basis of the depiction of obstacle information not contained in the geo-database on the forward-looking display and provide database integrity monitoring.
- GPS navigation capability — This may be augmented by a DGPS to achieve the required accuracy.
- A declutter capability for the SVS display is required to effectively manage the information available versus the information of priority to the pilot's current task.

### 2.2.3 En Route Operations

The en route phase of flight is defined to begin at the Top of Climb (TOC) and end at the Top of Descent (TOD).

#### 2.2.3.1 SVS Enhancements to En Route Operations

SVS will support aircrews by helping them monitor flight performance and avoid hazards during the en route phase, as well as support their transition to descent and approach. This is especially true for low-level en route operations. In some situations and through various display implementations, SVS would also be used to rehearse an approach during the en route phase of flight (see Appendix B Applications *A-18. Simulation Training Fidelity* and *E-11. Mission Planning/Rehearsal*).

SVS will minimize dependence on alerting and escape maneuvers. However, there may be restrictions on the manner in which an SVS system may be used to emulate capabilities of visual flight. There will be a backup capability to support safe operation should an SVS system failure occur.

#### 2.2.3.2 Using SVS to Prevent CFIT in En Route Operations

SVS will include alerts that proactively warn the pilot of a projected flight path nearing prominent terrain or obstacles. As a backup to a terrain and obstacle database system, the system would have sensors that recognize terrain and other obstacles in the projected path of the aircraft and alert the pilot with visual and audible warnings when such hazards become imminent. These alerts would be provided through SVS integration with TAWS.

#### 2.2.3.3 Candidate En route Display Features

- Enhanced path guidance (e.g., tunnel- or pathway-in-the-sky)
- Boundaries of terminal defined airspace, and special use airspace
- A view of relevant traffic
- Appropriate weather hazards
- Prominent terrain that must be cleared (especially for low-level en route)
- Primary flight information

## 2.2.4 Arrival and Approach Operations

The arrival phase begins at the TOD where the aircrew leaves en route flight, continues through descent, and transition to the airport terminal area for an approach. It ends after landing when the aircraft departs the runway. Approach operations have longitudinal and lateral spacing requirements, speed and descent profiles, and weather minimums that impose restrictions on the arrival to an airport. The responsibility for in-trail and lateral spacing from designated aircraft can be transferred from ATC to aircraft operating in VMC. Pilots may then maintain visual separation from traffic they are following, from parallel runway traffic, and from other traffic within their field of view. In IMC, separation is currently controlled by ATC, and approaches are not conducted when the weather is below minima.

During MC, to continue the approach below the decision height (DH), the pilot must see at least one of the following references: the approach lights; the runway threshold, its markings or lights; the runway end lights; the touchdown zone, its markings or lights; a visual approach slope indicator; the runway, or its markings or lights. Using an autoland system in an autocoupled approach, the pilot performs system checks at prescribed alert heights (AHs) and is able to land in CAT IIIb visibility.

### 2.2.4.1 SVS Enhancements to Arrival and Approach Operations

SVS could allow for the substitution of visual landing criteria when certain components of the approach system are inoperative or unavailable. For example, SVS equipped aircraft could continue to lower minima even when approach lights are inoperative. If runway edge lights are inoperative, restricting airfield use, SVS could enable operations without that restriction, thus improving operational reliability and helping to provide the economic incentives for SVS to “buy its way onto the flight deck.”

SVS precision navigation guidance would provide an additional integrity thread for on-board navigation systems. For example, SVS would augment glideslope and localizer information and verify the precise runway location and alignment. This would allow lower visibility or DH minimums using an Instrument Landing System (ILS) that meets accuracy requirements for CAT III minimums, but does not have either the integrity checks or monitoring required for Type III installations. Below the normal (non-SVS) minimums, a discrepancy between the ILS readout and the SVS image would necessitate performing a missed approach. As SVS technologies mature and are certified to higher standards, lower minimums would be allowed using SVS in place of an ILS. A conceptual SVS display of a DFW approach is depicted in Figure 2.2. Although initial SVS installations may supplement existing approach navigation aids, mature implementations could be the primary navigation aid for precision RNP operations. SVS will enable the pilot to maintain sufficient path accuracy to make the approach.



**Figure 2.2 Notional SVS Display of DFW Approach**

SVS will enable aircraft to maintain virtual visual separation from designated traffic while executing the approach to landing. Part of the virtual visual environment is the depiction of traffic not only on a plan-view ND, but also on a HDD or HUD with terrain, obstacles, and weather hazards. This depiction of traffic, would be needed to accept separation responsibility from ATC. Range information will be included with the iconic traffic depiction. To achieve the efficiencies associated with visual approaches using visual separation in IMC, the equivalent VFR criteria for these approaches to single and parallel runways must be met.

Any terrain, obstacles, or traffic that would impinge upon the intended approach and landing path must be visible in the SVS. The EVS component of SVS would be used as an integrity monitor of the database depiction of such hazards in this critical flight phase.

### *Single Runway Approach*

Aircrew will follow path guidance depicted on the HDD or HUD. Weather hazards and traffic information are also displayed on both the forward-view PFD or HUD and the plan-view ND. Terrain imagery would enhance the flight crew's situation awareness, and, together with pathway guidance and TAWS alerting, supplement the aircraft's CFIT avoidance capability. If the aircraft is following another aircraft in-trail, separation could

be maintained using an on-board spacing tool.\* To perform a virtual visual approach in IMC, the pilot would acknowledge, “seeing” the traffic. A spacing tool would be used to maintain separation down to runway touchdown. Landing in IMC, the PF would use the virtual visual display for guidance and visual references of terrain, infrastructure, and the airport. SVS will display runway perspective and visual cues sufficient to make a virtual-visual landing (section 2.2.4). Obstacles and traffic on or near the runway would be shown in a forward view so that avoidance or missed approach maneuvers are supported in IMC as well. With this virtual visual capability, SVS will support pilots in performing low-visibility approaches without an ILS.

### *Parallel Runway Approaches*

When both aircraft are SVS equipped, virtual-visual approaches in IMC are analogous to visual approaches to parallel runways closer than 4300 feet using visual separation from adjacent traffic. Since these approaches are not controlled by conventional ATC radar, it is important that they are supported by additional technology and alerting capability. The AILS concept, which uses ADS-B information, is one such multi-level alerting system that supports pilots in keeping two similarly equipped aircraft on close parallel paths, and incorporates an emergency escape maneuver to avoid intrusion. SVS would enable *independent* parallel approaches in suitable environments.

Similar to a single runway approach, the pilot would acknowledge seeing the traffic, depicted on the SVS display<sup>†</sup>. Both aircraft would be advised by ATC that separation control had been transferred to the cockpits (of the SVS equipped aircraft). The same spacing tool used for in-trail spacing could also give longitudinal spacing information, while range information would be available from the traffic icon. An AILS system incorporated into SVS would provide enhanced safety for these virtual-visual parallel approaches. It would also function as a reversionary mode to the SVS virtual-visual parallel approach procedure. AILS has been demonstrated to support parallel approaches down to runway separations of 2500 feet.

### *Circling Approaches*

Circling approaches are required when the landing runway is not aligned with the instrument approach course. During a circling approach, the aircraft is flown visually, below the cloud ceiling, to the landing runway. SVS will provide guidance to assist the pilot during this maneuvering. SVS will also allow circling approach visibility minimums to be reduced to that of straight-in approach minimums while maintaining or increasing safety. Similarly, SVS will help reduce RNP minima – especially for IMC approaches to terrain challenged airports.

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\* Research into the implementation of a “spacing tool” is also being conducted at NASA LaRC under the Advanced Air Traffic Technology (AATT) project.

<sup>†</sup> Depicting adjacent aircraft on SVS displays could be accomplished in several ways and remains an open research issue.

### *Published Visual Approaches*

These approaches following terrain features (e.g., DCA river approach) are performed during VMC. SVS equipped aircraft could make this approach in IMC. The pilot would follow the pathway-in-the-sky guidance overlaid on the display of terrain depicting the features that define the approach. SVS would also improve a pilot's awareness of noise abatement procedures through an intuitive display of the aircraft's ground track in relationship to the noise abatement area.

#### 2.2.4.2 Using SVS to Avoid CFIT on Approach

SVS provides a view of the terrain along the path of the aircraft very much as is the case on a clear day. Coupled with TAWS, the SVS forward-view provides additional proactive CFIT protection. SVS will give valuable cues to prevent initiating an early, or late, descent that may result in landing short, or long. The primary expectation is that the pilots flying the aircraft will not fly into a hillside, mountain, or other terrain while looking at the clear-day view provided by SVS. As a backup, the system will have EVS sensors that detect terrain and other obstacles in the projected path of the aircraft and alert the pilot with visual and audible warnings when such hazards become imminent. Precision navigation approaches that maneuver around significant terrain or obstacles would require the incorporation of EVS sensors for database integrity monitoring to enable low-visibility operations. The procedures related to this feature will prescribe a course of action to be taken when warnings are issued. The warnings will be designed such that appropriate time is available to allow a flight to divert its course either by climbing to a higher altitude or deviating around the impending hazard.

#### 2.2.4.3 Using SVS to Prevent Runway Incursions on Approach

SVS will depict potential RI situations and provide cueing, alerting, and resolution guidance to prevent, warn of, and avoid RIs by other aircraft, ground maintenance and support vehicles and, potentially, ground crew and wildlife (Figure 2.1 and Reference 1).

#### 2.2.4.4 Candidate Arrival and Approach Display Features

A majority of the features described for departure operations (section 2.2.2.4) are also applicable to the approach phase. Some features of particular interest are:

- The runway edges and centerline
- Weather hazards such as windshear, thunderstorms, turbulence, in the approach path
- Wake vortex hazards
- Obstacles on and adjacent to the runway: construction, aircraft, wildlife, ground support vehicles and personnel
- Terrain such as mountains and hills that are factors influencing the arrival or approach
- A flight path predictor, showing proximity to terrain, obstacles, and traffic

- Guidance presenting an optimal path for the crew
- Path compliance monitoring and alerting
- An alerting capability that warns the pilot of prominent terrain — This may be similar to current TAWS capabilities, but should include more proactive or strategic protection. If alerting features are used, recovery procedures for dealing with alerts must be incorporated.
- A proximate traffic advisory and alerting capability including resolution procedures
- A graphical depiction of the terrain, airport, and significant infrastructure, driven from a terrain database — This imagery would be shown in a forward-view HDD or HUD. Current PFD symbology, including path guidance, would be superimposed on the database images.
- CDTI — This would be a plan-view HDD of the flight path and relative location of traffic. Current ND symbology will be included in this display and integrated into the virtual visual forward-view.
- Forward-looking sensors, using FLIR, enhanced weather radar, or MMWR technology — The data from these sensors, not necessarily the raw images, would be the basis of the depiction of obstacle information not contained in the geo-database on the forward-looking display and provide database integrity monitoring.
- GPS navigation capability — This may be augmented by a DGPS to achieve the required accuracy.
- A declutter capability for the SVS display is required to effectively manage the information available versus the information of priority to the pilot's current task.

### 2.2.5 SVS Support to Non-normal Operations

SVS will provide intuitive visual support to pilots in non-normal and emergency situations. During loss of control and non-normal scenarios, where crew attention is diverted, SVS could provide improved awareness of their position relative to terrain and obstacles. The likelihood of mistakes with systems and/or navigation tasks due to high workload will be reduced. SVS features for these types of situations could include:

- Visual cues for upset recognition and recovery
- Airport and runway diversion planning
- Traffic and weather hazard deconfliction during engine out drift down
- Improved emergency descent awareness of terrain, traffic, (descent caused by engine out, depressurization, smoke/fire)
- Enhanced SA during recovery from loss of control
- Depiction of missed approach guidance

- Depiction of emergency approach terrain and obstacles
- Intuitive emergency procedure support and guidance

### 3 Benefits

SVS is an integration of several technologies that possess identified or assumed safety and operational benefits of their own. The increased benefits of SVS beyond those of the individual components will be realized as a result of the *integration* of the individual technologies.

#### 3.1 Potential Safety Benefits of SVS

SVS is expected to emulate day VMC in limited visibility conditions. Using SVS, the overall accident/incident/loss rate is expected to be that of day VMC. Some of the expected safety benefits are:

- CFIT reduction
- RI reduction
- Improved situation awareness
- Improvement of unusual-attitude/upset recovery
- Improved non-normal situation response (section 2.2.5)
- Improved compliance with ATC clearances

#### 3.2 Potential Operational Benefits of SVS

An SVS operational benefits analysis was completed in a contracted study for NASA (Appendix E and Reference 6). That study identified a number of areas where significant benefits can be achieved using SVS in CONUS operations. The conclusions from the study are summarized below with excerpts taken from the final report.

Synthetic vision systems should provide several improvements in airport terminal area operations. Among these are reduced arrival and departure minimums, use of additional multi-runway configurations, independent operations on closely spaced parallel runways, and reduced arrival spacing. Using modified versions of airport capacity and delay models previously developed for analyzing other NASA technologies, a reduction in arrival and departure delay by implementing various SVS capabilities was estimated. The analysis results indicate that SVS technologies should provide large economic benefits, but that different capabilities are important at different airports.

Modeling of a select number of airports has shown SVS to provide the following benefits:

- Independent operations on closely-spaced, parallel runways — Modeling shows significant benefits, particularly at DTW, MSP, and SEA.
- Reduced inter-arrival separation — Modeling shows benefits at all airports, with particularly large benefits at ATL and LAX.
- Converging and Circling approaches — Modeling shows large benefits at ORD and EWR, and significant benefits at MSP and DFW.

- Reduced Departure Minimums — Some benefits are indicated, in the ranges \$3 million/year at Minneapolis, \$51 million/year at Seattle.
- Reduced Runway Occupancy Time — 20% reduction in low visibility conditions
- Potential for Reduced Training requirements
- Potential for Reduced Arrival Minimums — Using SVS for RNAV and RNP procedures into Type I airports may be the subject of a future operational benefits study.

## **4 Issues**

Prior to publication, a draft of this document was released to participants of the February 2000 workshop and other stakeholders for comments. Many of the responses were incorporated into the current version. The remaining comments describe open issues related to the design and use of SVS that need to be resolved during future research and development. A representative summary of those comments, grouped by area of concern, is presented here. A list of the constituent issues, questions, and comments is provided in Appendix F.

### *Benefits, Risks, Cost*

Is SVS the optimal solution to the problems associated with low visibility operations?

Will SVS be cost-effective?

What risk factors are associated with SVS implementation?

### *Displays*

What levels of control will pilots have over display format and content?

How should the flight path and guidance be presented?

What are the SVS field-of-view requirements?

How will SVS displays adhere to existing cockpit display philosophies?

How will sensor and database information be integrated and displayed?

How will SVS displays be integrated with existing flight deck displays?

What are the implications of displaying information on head-down and head-up displays?

What is the best way to provide alerts for runway incursion threats and resolution guidance?

How can SVS depictions of potential RI traffic provide maximum safety benefits?

### *Human Factors*

How will SVS adhere to established human factors precepts in the display of information?

How will known and anticipated flight crew performance issues be addressed in the design of SVS?

Can SVS be shown to improve crew situation awareness?

### *Procedures*

How will SVS affect terminal area procedures and the roles of pilots and controllers?

How will SVS procedures accommodate non-equipped or non-cooperating traffic?

How will emergency procedures be affected by SVS?

### *Simulation*

How can SVS technologies contribute to improved visuals in flight simulation?

What enhancements to weather hazard depiction can SVS provide, both in simulation and in actual flight?

### *Sensors, Databases*

How can the performance of enhanced vision sensors, such as FLIR and MMWR, be evaluated, modeled and enhanced?

How will sensor performance be compared to VMC viewing?

How will SVS integrate data from sensor and database sources?

What types of ADS-B data would best contribute to the elimination of RI accidents?

How will SVS ensure data integrity, reliability, and currency?

## 5 Conclusions

Current technology allows aircrews to perform all-visibility en route operations as well as low visibility approaches and landings to appropriately equipped runways. SVS will further increase aircrew SA and performance by integrating existing and new technologies and flight procedures into a *virtual visual environment* which expands safety and operational benefits in CaB ground operations, departure, en route, and arrival/approach. The key safety benefits for applying SVS are preventing CFIT and RIs and the key areas of operational benefit are supporting low-visibility ground operations, departures, and approaches. SVS could also enable pilots to fly more flexible approaches in low-visibility, e.g., RNAV and RNP procedures to Type I or non-ILS equipped airports. SVS and the virtual visual environment are well suited to provide both safety and operational benefits in these phases of flight. Therefore, the CaB industry should pursue development of SVS technology to help overcome these operational limitations in low-visibility conditions. Several research application areas and issues that may offer effective SVS benefits are presented in the following list. These particular applications were selected because SVS offers benefits in both normal and terrain challenged airports and in visibility ranging from VMC down to IFR CAT IIIb.

Ground Operations – to enable VFR rates of operation in visibility as low as 300 ft RVR

- Taxi Operations (precision navigation and guidance)
- RIPS

Departure

- Operations at Type I and non-ILS runways
- Parallel Departures
- Self-Spacing Capability
- Curved Departures

En Route Operations

- Low-level En Route operations
- En Route Diversion

Approach (Arrival) Operations

- Approach Operations to Type I and non-ILS runways
- Converging Operations
- Parallel Approaches
- Curved Approaches (Includes RNAV, RNP)
- Circling Approaches
- Self-Spacing Capability

- HSALT

#### Non-Normal Operations

- Upset recognition and recovery
- Emergency descent support/guidance
- Recovery from loss of control
- Emergency approach terrain/obstacle awareness
- Emergency procedure support/guidance.

Government agencies should provide R&D assistance and the required communications, navigation, and surveillance (CNS) infrastructure for SVS to achieve its potential benefits. The development, implementation, and updating of terrain and obstacle databases used by SVS also require government and industry leadership to ensure data accuracy, reliability, and integrity. EUROCAE Working Group 44/Joint Special Committee RTCA 193 continues to develop database requirements that will be used by SVS. SVS could also have profound regulatory implications. In fact, the difference between seeing another aircraft in VMC and “seeing” that same aircraft with SVS not only presents challenges to certification, but might lead to an entirely new “electronic flight rules” or EFR world. As a result, in-depth discussions between researchers, the FAA, and any other agencies involved in certification should begin immediately.

As with the advent of glass cockpits and flight management computers two decades ago, SVS presents an opportunity to create an environment where many traditional paradigms are replaced with entirely new concepts. Extensive research, experimentation, and collaboration with stakeholders will determine the optimal mix of SVS technologies with existing and proposed capabilities and must address a multitude of human factors issues. This approach will ensure that SVS will enhance safety and enable consistent gate-to-gate aircraft operations.

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Part 25 – Airworthiness Standards: Transport Category Airplanes  
Part 23 – Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes  
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Traffic separation standards  
Terrain clearance standards  
LAHSO rules  
Parallel approach standards  
Precision approach standards

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## Appendix A – Visibility Categories

Figure A-1 depicts the published Instrument Landing System (ILS) approach minima. Specific approach procedures often require the use of a higher Decision Height (DH) and/or Runway Visual Range (RVR) and are according to Part 91.189. Equipage is according to Appendix A to Part 91.

ILS Minimums (with all required ground and airborne systems components operative)		
	<u>DH (feet)</u>	<u>RVR (feet)</u>
• Category I	200	2400
• Category I	200	1800 (with touchdown zone and centerline lighting)
• Category II	100	1200
• Category IIIa	0-100*	700
• Category IIIb	0-50*	150-700
• Category IIIc	0	0

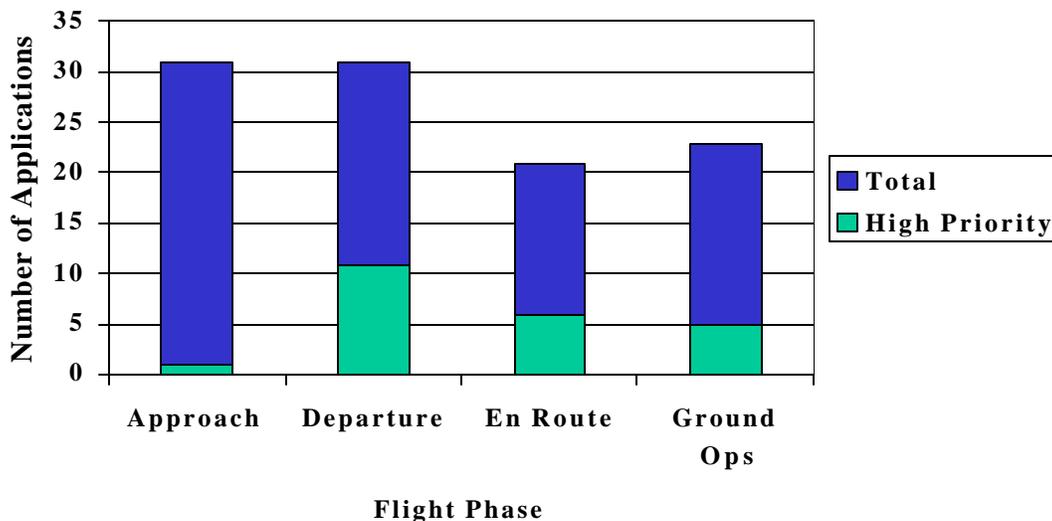
\*Alert Height  
Note: Special Authorization and equipment required for Categories II and III.  
Reference: Aeronautical Information Manual, section 1-1-9 i.

**Figure A-1 Visibility Categories**

## Appendix B – CaB SVS CONOPS Applications

There were a number of applications considered at the February 2000 SVS Workshop. These had been either listed on a work sheet distributed to participants by the NASA SVS CONOPS Team for consideration, or added by the participants in the workshop. The applications were considered in terms of phase of flight and were later organized into a structure in the following categories: (1) Hazard Avoidance; (2) Self-Separation; (3) Emergency Management; (4) Improved Operational Capability/Piloting Aids/Enhanced Flight Management; and (5) Navigation.

This appendix is divided into sections that present the applications addressed by the workshop participants in four flight phases: (1) Approach, (2) Departure, (3) En Route, and (4) Ground Operations. The first page of each section presents a numbered (for reference) list of the applications considered, separated into the five categories listed in the preceding paragraph. Next in each section, the documentation presents a description and notes on each of the applications. The notes are either comments from the workshop or attempts of the SVS team members to describe the application. They are included with minimal editorial modification. Three asterisks (\*\*\*) are placed after the application title when a high priority rating was given to the application. See also Figure B-1.



**Figure B-1 SVS Applications Identified During Feb 2000 Workshop**

## B.1 Approach

### Hazard Avoidance (Non-traffic hazards)

- A-1. *Emergency Situations in Challenging Terrain*
- A-2. *Bird Strikes*
- A-3. *Hazardous Weather Avoidance*
- A-4. *Wake Turbulence IMC*
- A-5. *Terrain Avoidance Equivalent to VMC*
- A-6. *Terrain Information to Controllers*

### Self Separation (SS)

- A-7. *De-Conflict Approaches*
- A-8. *Identify Traffic Ahead*
- A-9. *Self Separation*
- A-10. *LAHSO*
- A-11. *Runway Incursions*

### Parallel Approaches

- A-12. *Closely Spaced*
- A-13. *Self Contained Parallel Approaches*
- A-14. *Station Keeping (Parallel approaches)*

### Emergency Management

- A-15. *Upset Recovery*
- A-16. *Missed Approaches*

### Improved Operational Capability/Piloting Aids / Enhanced Flight Management

- A-17. *Transition from Instruments to Visual Flight*
- A-18. *Simulation Training Fidelity*
- A-19. *Runway Remaining*
- A-20. *Crew Resource Management (CRM) HUD/HDD - This one might be more of an issue than an application*
- A-21. *Potential for Hand Flown Approaches*
- A-22. *Reduced Minima\*\*\**
- A-23. *Required Time Arrivals*
- A-24. *Flare Guidance*

### Navigation

- A-25. *Altitude Deviation*
- A-26. *Curved Approaches*
- A-27. *Guidance (symbols)*
- A-28. *Improved Approaches in Challenging Terrain*
- A-29. *Path Accuracy / Noise Abatement*
- A-30. *VASI (Self contained)*

## **Descriptions and Notes**

### **Hazard Avoidance (Non-traffic hazards)**

#### *A-1 Emergency Situations in Challenging Terrain*

In this application the crew will be given information in the synthetic/enhanced vision display that will depict the terrain to aid in emergency situations while flying into challenging terrain. Such information could be derived from a database designed to give an accurate depiction of the approach terrain surrounding the airport. The database will have the runway in view with all the current obstacles and traffic. It would use an enhanced version to show the runway traffic. The enhanced version will also allow the crew to see the runway from the time they rollout on final. It would allow the crew to view the terrain and make decisions during an emergency situation that would aid in avoiding the challenging terrain.

It is possible that an accurate database would give the crew the means for viewing the challenging terrain. NASA along with NIMA utilized the shuttle to obtain a high-resolution digital topographic and image database of the Earth during a recent shuttle mission. It is expected that this information could be used to generate the database necessary for the SVS display in the flight deck. This would allow the crew to see the terrain, judge its location, and avoid possible hazards associated with the terrain during an approach or an emergency situation in challenging terrain.

Terrain, obstacle, and related flight information data is available from a variety of Government and private sector sources, such as, NIMA, ICAO, FAA, USGS, NGS, Jeppesen Sanderson, and a variety of other companies in the commercial mapping, satellite and aerial survey industries. The potential for using 3D and 4D imagery could also be included in the display information for the application.

#### *A-2 Bird Strikes*

In this application, the synthetic/enhanced vision display could be used to detect birds or other unknown objects in the approach airspace or runway area. Some type of sensing device would be needed since a database would not show the birds or objects.

#### *A-3 Hazardous Weather Avoidance*

This application could consist of display of weather from a database and from onboard weather radar sensors. The information could be acquired from a ground-based database and up linked to the flight deck. In an SVS application the information would be displayed in the flight integrated with other data-base and sensor-derived information. The display would integrate hazardous weather information with traffic and terrain information for use during an approach. It could also propose a safe route through the hazards by incorporating either conventional logic or artificial intelligence to determine such a route. It could also incorporate decision aids to assist the flight crew in making a decision to continue the approach or divert to an alternate airport.

#### *A-4 Wake Turbulence IMC*

In this application the pilots operating in the terminal area will be provided with sufficient information in a synthetic/enhance/artificial vision display to prevent wake turbulence encounters. The synthetic vision capability will provide the pilot an accurate view of where the potentially hazardous traffic is. Such information cannot be derived purely from a database. Information being sensed on the ground and perhaps onboard technology could function together to acquire the necessary information. ADS-B could be used to accurately define the three dimensional location of traffic and its movement. The pilot would provide the decision-making and control needed to avoid wake encounters similar to how that task is performed in VMC.

A means of sensing or predicting the location of potentially hazardous wake turbulence will be used in this application. The AVOSS program at NASA undertook developing a ground-based system. If the sensing or prediction technology is ground based, the SVS application would utilize a data linking capability to provide necessary information to aircraft in flight. A display of traffic could allow the pilot to maintain a safe distance behind a leading aircraft, judge the probable location and intensity of its wake field, avoid crossing the path of such fields, and fly above potentially hazardous fields to avoid encounters as in VMC during visual parallel approaches.

In this application, as opposed to IMC operations where aircraft are longitudinally spaced according to the weight/type classification, the pilots would be given the responsibility for in-trail spacing. The flight deck display would provide information similar to the view of the traffic available to pilots in VMC. The potential for using symbols and alphanumeric display information may also be included in such an application.

This application may also be used in departure.

#### *A-5 Terrain Avoidance equivalent to VMC*

This is a central application of SVS. In the words of NASA Langley's Mike Lewis, SVS should "make every flight the equivalent of clear-day operations." Dan Baize has stated the goal of SVS in this way, "Provide a clear-day, out-the-cockpit view to pilots flying in any visibility or lighting conditions." Stephen Pope wrote in the September, 1999, edition of the *Aviation International News /Online*, "As currently envisioned, synthetic vision will provide a detailed scene of the outside world on primary flight displays (PFD) with overlays of heading, airspeed and altitude on vertical and horizontal tapes. An artificial view would be presented on the PFD, with mountains, hills, obstacles and airports rendered precisely." Especially when coupled with weather and traffic information, such an integrated system would improve situation awareness and could help reduce aviation accidents caused by CFIT and runway incursion.

The most intuitive display of terrain information would probably take the form of a photo-realistic, possibly full-color presentation using an oblique, forward-looking point of view. This egocentric point-of-view would enhance the pilot's sense of spatial orientation in the approach (tactical) airspace. Terrain and approach symbology would be presented on a full-color, flat panel LCD or possibly on a modified CRT. While flying in any visibility condition less than perfect VMC, the pilot would be able to view the approach environment (including mountains, hills, traffic, obstacles and airport details) in

the same way as would be possible under ideal visual conditions. Even during visual approaches the SVS could clarify the location of critical terrain features and improve SA. By relying on accurate terrain database information, this application would provide 1) topographical imagery suitable for aerial navigation, and 2) adequate warning of dangerous proximity to terrain. Moreover, a complete SVS would also provide sensor detection and display of obstacles (enhanced vision), data link of traffic information and the flight path of the aircraft.

#### *A-6 Terrain Information to Controllers*

This does not appear to be an airborne synthetic vision application. Some participants in the SVS workshop highlighted that there is also a need for synthetic vision technology in displays for ATC controllers. Possibilities include 1) providing the same 3-D display of terrain database and enhanced vision information to controllers that would be available to pilots flying SVS-equipped aircraft; 2) comparing airport-based radar sensors to DGPS and other positional information to verify aircraft locations on the ground. In its ideal form this application could provide a 3-D “God’s-eye” view of the approach (or departure/en route) airspace and traffic to controllers, including accurate terrain database and obstacle information. This application would extend ATC display capabilities beyond the current 2-D plan and vertical profile presentations.

### Self Separation (SS)

#### *A-7 De-Conflict Approaches*

An application that would provide guidance to an aircraft to avoid a conflict, either with other traffic, terrain or obstacles. When the system detects that the current flight path has a potential conflict, an alternative route is displayed for the pilot to use to avoid the conflict.

#### *A-8 Identify Traffic Ahead*

Information provided by SVS equipment will allow the flight deck crew to identify and/or see the traffic that is ahead.

#### *A-9 Self-Separation*

A synthetic vision display system would allow pilots to manage their in - trail separation in instrument as well as visual approaches. Separation distances based on carrier class might be made more realistic using wake turbulence and runway occupancy information. This information could be datalinked to the cockpit. ADS-B state information from surrounding aircraft could be displayed in a format that allows management of separation from any chosen target aircraft. Separation guidance could be distance and/or time based with symbology appropriate to determine and improve performance. Guidance might be shown on the ND and be capable of being followed by the autopilot. The application was given a high priority rating.

### *A-10 Land and Hold Short Operations (LAHSO)*

This application would provide graphical overlays of symbology and deceleration factors required for LAHSO. An SVS display could provide several improvements over current guidance technology, including accurate positioning of the hold short line and a dynamically-calculated aircraft stop point symbol (“football”) upon the photo-realistic runway scene. Presentation of numerical information, such as the Criticality Factor (ratio of ‘estimated’ vs. ‘available’ stopping distance), would be provided on a HUD or PFD. The ND would show the own-ship location along the arrival runway in a plan or “God’s eye” view. The entire SVS LAHSO implementation would be a highly integrated display with multiple algorithms. This display could also include distance from threshold, distance to hold short point, ramp speed of selected exit prior to hold short point, wind direction and magnitude, desired and actual aircraft deceleration, ground speed, proximate aircraft, etc.

### *A-11 Runway Incursion*

This application addresses the problem of one aircraft on the final approach to a runway and a second aircraft, on the ground, taxiing onto the intended landing runway of the first aircraft. This could be the result of a pilot error in misunderstanding a clearance or a controller error. The intruding vehicle could also be a truck or other surface vehicle. An erring aircraft could be preparing for a take off, in the process of taking off, or taxiing to or from a ramp and crossing the runway. In a number of ways this is similar to the problem of an in-flight traffic conflict. However, it is incumbent upon the approaching aircraft to maneuver to safety given that the erring aircraft has not cleared the intended runway within some amount of time prior to the scheduled landing. If the intruding aircraft is in the process of taking off, the problem becomes even more similar to the parallel approach applications studied in the AILS problem. The approaching aircraft would be required to maneuver to safety, probably executing a missed approach.

The SVS system would function to provide an image of the intruding aircraft as it taxis on the runway. The system would also incorporate cockpit alerts to warn the pilots both on the ground and in the approaching in-flight aircraft as the incident is evolving. The alerting could include a cautionary alert followed by a warning signaling the flight crew of the approaching aircraft to execute a missed approach.

The amount of equipment required on both aircraft or vehicles would depend upon the details of an implementation decided upon. The surface vehicles including taxiing aircraft may be required to simply broadcast their position on the surface at all times. Alternately, some vehicles positions could be detected by radar either onboard the approaching aircraft or on the ground and data linked to the approaching aircraft.

Some of the elements of this application would also depend upon the environment in which it is implemented, in particular in IMC or VMC. An important consideration in designing this application will be to determine the role of the tower controllers. They will require displays of the best available information on the surface vehicle movement as well as any information and alerts presented to the aircraft, including a command to execute a missed approach. (This application was given a high priority by two of the groups at the SVS workshop)

### *A-12 A-13 A-14 Parallel Approaches*

Simultaneous approaches to parallel runways during instrument flight rules (IFR) conditions is an application that has been addressed from both a ground (Precision Runway Monitoring) and a flight deck (Airborne Information for Lateral Spacing) perspective. Solutions might use both dependent techniques such as a paired staggered approaches and independent techniques such as the flight deck based lateral spacing system used in the AILS research.

Crucial to the parallel approach application is an ability to maintain both lateral and longitudinal separation from parallel traffic. This capability would be enhanced with more accurate DGPS position data, as well as better traffic position information as provided by the ADS-B system, and an ability to see traffic. An SVS system that provided a crew with traffic visualization in IFR conditions, as well as self separation symbology on a CDTI display, and/or with AILS display capability could make simultaneous parallel approaches in IFR feasible.

### Emergency Management

#### *A-15 Upset Recovery*

Recovering from upsets such as might be induced by wake turbulence or some other atmospheric phenomena, is easier for pilots in VMC when they can see features such as the horizon out of the window. If the pilot in an SVS flight deck is provided adequate real world like viewing by a display, performance in recovering from upsets could be similar to that in VMC. This will be applicable in all of the airborne flight phases.

#### *A-16 Missed Approach*

When a landing cannot be accomplished while executing an instrument approach a published maneuver referred to as a missed approach is available to put the pilot in a more favorable position to exercise other alternatives to landing. Protected obstacle and terrain clearance areas for missed approaches are predicated on the assumptions that the aborted approach is initiated at the point and altitude prescribed. Reasonable buffers are provided for normal maneuvers; however, no consideration is given for an abnormal turn out. Also, weather is certainly a factor in flying a missed approach and could influence a pilot to deviate from the published maneuver.

### Improved Operational Capability/Piloting Aids / Enhanced Flight Management

#### *A-17 Transition from Instruments to Visual Flight*

The transition from instrument flight to visual flight is not always a smooth process. Especially if there is traffic and terrain considerations to contend with when the transition occurs. With SVS this transition could be very smooth making for a more comfortable and safer approach.

### *A-18 Simulation Training*

Flight simulators could benefit from an SVS terrain database and imaging capability. The increased realism achievable from using valid terrain and obstacle data as well as recorded or live weather information displayed in real time could enhance training for normal and non-normal flight scenarios. Simulated traffic could be presented in a forward-view display as well as on the ND. This capability of rendering an artificial environment reasonably faithful to any proposed location is the same tool that would be used in the mission rehearsal application. The imagery and symbology would be the duplicate of the actual synthetic environment thereby increasing the fidelity of the simulation.

### *A-19 Runway remaining*

In this application, the synthetic/enhanced vision system would display the runway remaining. A distinction should be made in the display between raw (real) data and computer (imagery) generated data.

### *A-20 CRM HUD/HDD*

In this application, the synthetic/enhanced vision system would provide the flying pilot with a Head-Up Display of the extended runway centerline. The PNF would be provided with a detailed map on the navigational display. The database will have the runway in view with all the current obstacles and traffic. It would use an enhanced version to show the runway traffic.

### *A-21 Potential for Hand Flown Approaches*

This application provides the ability to fly the approach in IMC in a manner similar to flying the approach in VMC. This includes hand flying the approach and not having to rely solely on instruments or an auto-coupled approach.

### *A-22 Reduced Minima \*\*\**

Currently no pilot may operate an aircraft at any airport below the authorized minimum descent altitude or continue an approach below the authorized decision height unless the aircraft is continuously in a position from which a descent to a landing on the intended runway can be made. That is, the pilot must see the runway or some visual reference to the runway. Further, for CAT II and III approaches the visual reference requirements are even more stringent. An SVS may allow approaches in lower minimums before requiring direct visual references.

### *A-23 Required Time Arrival*

This refers to aircraft flying over inbound fixes at prescribed times. Required time arrival would be more beneficial for the terminal controller than the en route controller. There is less latitude for the terminal controller to make up time differences for sequencing for approaches than there is for the en route controller to have the aircraft fly over a crossing fix and arrive at an inbound fix on time.

### *A-24 Flare Guidance*

Flare guidance is provided through the flight directors on the PFD. An SVS display system adds the ability to see the runway synthetically in low visibility conditions. This enhances the crew's situation awareness.

### Navigation

### *A-25 Altitude Deviation*

It was not altogether clear what was intended by this topic included in the notes presented by one of the groups at the SVS workshop. An altitude deviation clearly refers to the failure of a flight to maintain the altitude assigned by ATC. Deviation from an electronic flight path may also be classified as an altitude deviation. One possibility of an SVS application might be to alert the pilots of an altitude deviation and provide guidance to correct the deviation. It is not clear that an SVS would be required to perform this function, however.

### *A-26 Curved Approaches*

SVS can support Area Navigation (RNAV) and Required Navigation Performance (RNP) approach procedures. These procedures provide expanded operational capability in comparison to traditional straight-in ILS approaches. SVS with its increased SA enables safe flight of these procedures.

### *A-27 Guidance (Symbols)*

This application addresses the use of synthetic vision to replace or supplement the guidance information currently included in the PFD. It would therefore provide an alternative to flying flight director and other information currently presented in primary flight display instruments using real-world-like information of the type pilots acquire in VMC out-of-the-window flying. This application is related to another proposed application referred to as terrain referenced navigation. The primary difference will possibly be that instead of photo-realistic illustrations being incorporated in the display, the information presented will be in the form of symbols.

Implementing such an application during approaches requires an accurate database of terrain to support visual navigation and an acceptable representation of the horizon to aid in keeping the wings level and turning. Pilots would operate similarly to the manner they operate in VMC except that the situation information will be provided by information presented as symbols on the display. The information will be displayed on the PFD, ND, or HUD. A variety of other innovative display technology methods could also be used.

Requirements to support this application also include accurate navigation information that will enable the pilot to discern own ship location, such as could be provided by GPS or DGPS. The display will depict the location of the own ship on a scene derived from the database.

This could be implemented as an independent support tool when it would not be a requirement for the approach.

### *A-28 Improving approaches in challenging terrain*

In this application the crew will be given information in the synthetic/enhanced vision display that will improve approaches into challenging terrain. Such information could be derived from a database designed to give an accurate depiction of the approach terrain surrounding the airport. The database will have the runway in view with all the current obstacles and traffic. It would use an enhanced version to show the runway traffic. The enhanced version will also allow the crew to see the runway from the time they rollout on final.

It is possible that an accurate database would give the crew the means for viewing the challenging terrain. NASA along with NIMA utilized the shuttle to obtain a high-resolution digital topographic and image database of the Earth during a recent shuttle mission. It is expected that this information could be used to generate the database necessary for the SVS display in the flight deck. This would allow the crew to see the terrain, judge its location, and avoid possible hazards associated with the terrain during an approach into an airport with challenging terrain.

Terrain, obstacle, and related flight information data is available from a variety of Government and private sector sources, such as, NIMA, ICAO, FAA, USGS, NGS, Jeppesen Sanderson, and a variety of other companies in the commercial mapping, satellite and aerial survey industries. The potential for using 3D and 4D imagery could also be included in the display information for the application.

### *A-29 Path Accuracy / Noise Abatement*

This application includes path guidance and energy management guidance in instrument as well as visual flight rules to enable a quieter approach, lateral guidance to move the noise footprint of the plane over less sensitive areas could be presented on a PFD or a HUD. A synthetic forward view depiction of noise sensitive areas to avoid might be presented. Noise reduction might be achieved using idle descent approaches where the pilot could be given energy guidance on the PFD. The vertical guidance would attempt to bring the plane to a location at a specific time at idle thrust.

### *A-30 VASI (Self contained)*

This onboard, self-contained VASI would supplement/replace ground-based visual glide slope indicators. The SVS display of this vertical guidance aid would be especially helpful in limited visibility or when airfield equipment is missing or inoperative.

## B.2 Departure

### Hazard Avoidance (Non-stationary / non-traffic hazards)

- D-1. *Weather/Windshear*
- D-2. *Wake Avoidance\*\*\**
- D-3. *Noise Abatement*
- D-4. *Bird Strikes*
- D-5. *SFO Runway 19\*\*\**

### Self-Separation and Spacing

- D-6. *VFR Separation\*\*\**
- D-7. *Runway/Path Incursion*
- D-8. *Aircraft Separation / Avoidance\*\*\**
- D-9. *VFR traffic Identification\*\*\**

### Emergency management

- D-10. *Engine Out/Emergency Situations*
- D-11. *Rejected Takeoff (RTO)*

### Improved Operational Capability/Piloting Aids / Enhanced Flight Management

- D-12. *Uncontrolled (feeder/divert) Airports\*\*\**
- D-13. *Reduced Minima\*\*\**
- D-14. *Triple and Quad Departures*
- D-15. *Smart Box (Enhanced flight Management)*

### Navigation

- D-16. *Terrain Navigation\*\*\**
- D-17. *Navigation (SIDs)\*\*\**
- D-18. *Non-Standard Go Around\*\*\**
- D-19. *Route Depiction\*\*\**

## **Descriptions and Notes**

### Hazard Avoidance (Non-stationary / non-traffic hazards)

#### *D-1 Weather/Windshear*

SVS could provide a 3D visualization of severe weather hazards including wind shear. If linked to wind shear detection and prediction equipment, SVS could display tactical as well as advisory information.

#### *D-2 Wake Avoidance\*\*\**

The description of this application is the same as that given in A-4. The two applications possibly should be combined into a single description such as the one provided in A-4. The application is of increased interest in closely-spaced parallel approach environments. It potentially has similar interest in the departure environment and could impact the ability of aircraft to depart on closely-spaced parallel runways.

#### *D-3 Noise Abatement*

This application includes path guidance and energy management guidance in instrument as well as visual flight rules to enable a quieter departure lateral guidance to move the noise footprint of the plane over less sensitive areas could be presented on a PFD or a HUD. A synthetic forward view depiction of noise sensitive areas to avoid might be presented.

This application is also applicable to the approach phase.

#### *D-4 Bird Strikes*

Preventing bird strikes is of high interest to aircraft operators. Of particular concern is the possibility of ingesting birds into jet engines that can result in serious damage and engine lost. This application would apply FLIR to detect birds in the airport departure areas and display the hazard to the pilots in a manner so as to aid in minimizing the possibility of a bird strike. The location of the birds would potentially be shown on the SVS display. This would also be a valuable application during approaches.

#### *D-5 SFO Runway 19L (closely related to terrain/navigation avoidance)\*\*\**

SVS can help guide through the SFO 19L departure navigation (tunnel in the sky) and overall can allow takeoffs in reduced visual minimums. 2000-foot terrain south of SFO can be depicted for hazard avoidance and noise abatement avoidance.

### Self-Separation and Spacing

#### *D-6 VFR Separation\*\*\**

A synthetic vision display system would allow pilots to manage their in-trail separation in instrument as well as visual departures. Separation distances based on carrier class might be made more realistic using wake turbulence information. This information could be

data linked to the cockpit. ADS-B state information from surrounding aircraft could be displayed in a format that allows management of separation from any chosen target aircraft. Separation guidance could be distance and / or time based with symbology appropriate to determine and improve performance. Guidance might be shown on the ND and be capable of being followed by the auto pilot.

*D-7 Runway/Path Incursion* See Approach Application A-11.

*D-8 Aircraft Separation/Avoidance\*\*\**

A synthetic vision display system would allow pilots to manage their in-trail separation in instrument as well as visual departures. Separation distances based on carrier class might be made more realistic using wake turbulence information. This information could be data linked to the cockpit. ADS-B state information from surrounding aircraft could be displayed in a format that allows management of separation from any chosen target aircraft. Separation guidance could be distance and/or time based with symbology appropriate to determine and improve performance. Guidance might be shown on the ND and be capable of being followed by the autopilot.

A synthetic forward view depicting terrain and obstacles, with icons identifying proximate traffic would provide the ability to maintain visual contact in IFR conditions.

*D-9 VFR traffic Identification\*\*\**

Traffic information in an SVS could be displayed on the ND and as icons in a forward view synthetic depiction of terrain. In VFR conditions traffic would be depicted on a CDTI-like navigation display using ADS-B information. The increased amount, accuracy, and frequency of the ADS-B data (over TCAS), would enable traffic icons to have more informative data tags, as well as potential added capability such as graphical trend information. This application has good value in all four phases of flight.

### Emergency management

*D-10 Engine Out/Emergency Situations*

This application incorporates in an SVS, information regarding the course of action, in particular the flight path to return to the airport in an engine out situation during departure. The path to follow will be generated by onboard algorithms using aircraft performance data and terrain and other airspace constraint database hosted information. The algorithms will also incorporate consideration of relevant weather information that will possibly be provided to the system via data link. The recommended path may be presented in the format of a tunnel in the sky or a path over the ground. The implication is that the SVS data will provide the course to pursue in a easily interpretable format for the pilots.

To develop this application, algorithms that can derive such a path for generic terminal environments, or airport specific algorithms will have to be developed and evaluated.

This application relates to the terrain navigation and noise abatement application (Departure application D-4). It could also enable aircraft to depart in unfavorable weather with increased capability to return to the airport in the event of an emergency.

This application is also applicable to en route and approach phases.

#### *D-11 RTO*

This application utilizes synthetic vision technology to assist the pilot in takeoffs by making rejected-takeoff information more convenient. This will be accomplished by integrating such information into the primary visual information being used. An SVS-based PFD or HUD would incorporate RTO information.

The information would be of the type conventionally displayed on the PFD in current operations or it would use more advanced formats of the nature developed in the NASA ROTO program. The information would be intended to provide improved situation awareness of runway remaining, and other parameters related to completing the takeoff. In addition to showing runway remaining, the information presented could include stopping distance calculations and incorporate related advisory displays.

### Improved Operational Capability/Piloting Aids / Enhanced Flight Management

#### *D-12 Uncontrolled (feeder/divert) Airports\*\*\**

A number of airports do not have an operating control tower. They are referred to as uncontrolled airports. As the term implies, traffic separation and sequencing is the responsibility of the pilots operating at that airport. Primarily, GA aircraft use uncontrolled airports, but on occasion CaB aircraft use these airports as a feeder airport or as a diversion airport. Egress and ingress to these airports, especially for IFR aircraft can conflict with uncontrolled VFR traffic. Also, these airports generally don't have a standard arrival or departure procedure making it very important to know the terrain and obstacles in the airport area.

#### *D-13 Reduced Minima\*\*\**

SVS can allow takeoffs in reduced visual minimums – CAT II/IIIa/IIIb with a potential for IIIc with emergency vehicle and gate operation support. One of the possibilities of this application is that by using synthetic vision capabilities, runways that are rated, for example as Type II, may be used in CAT IIIa conditions.

#### *D-14 Triple and Quad Departures*

Some airports have simultaneous departures, either on parallel or diverging routes. When more than two aircraft are departing in parallel, the situation becomes very critical if the middle aircraft has some sort of emergency and has to deviate from its standard path. It could drift into the path of the other departures creating a hazardous situation.

#### *D-15 Smart Box (Enhanced flight Management)*

SVS coupled with enhanced flight management capabilities can better support RNAV, and RNP procedures and potentially, real-time flight planning.

#### Navigation

#### *D-16 Terrain Navigation/Avoidance\*\*\**

Could also lead to emergency and noise abatement and aid in missed approaches. Using a terrain avoidance database a procedure would be developed to aid the pilot in CFIT conditions along with the synthetic/enhanced vision system. This application can also be used for approaches (see approach application A-28) and en route.

#### *D-17 Navigation (SID)\*\*\**

Supplement to departure application D-16.

SVS can help provide guidance through the SID navigation (tunnel-in-the-sky) and overall could allow takeoffs in reduced visual minimums – CAT II/IIIa/IIIb with a potential for IIIc with emergency vehicle and gate operation support.

#### *D-18 Non-Standard Go Around\*\*\**

All approaches have a published missed approach procedure (standard) that keeps the aircraft away from hazardous terrain and obstacles. In most cases, an aircraft that is executing a missed approach is given radar vectors (non-standard) by air traffic control in lieu of the missed approach procedure. This is done because of traffic or some other conditions the controller sees as being critical to a safe operation. The radar vector technique is also viewed as a more efficient way of managing traffic.

#### *D-19 Route Depiction\*\*\**

In this application the crew would be given information on the synthetic/enhanced vision display that would depict the route of the aircraft i.e. a tunnel in the sky. Such information could be derived from a database designed to give an accurate depiction of the departure terrain surrounding the airport. The database will have the runway in view with all the current obstacles and traffic. It would use an enhanced version to show the runway traffic. The enhanced vision will also allow the crew to see the runway from the time they rollout on final until departure. It would be used to prevent altitude deviations while in flight.

### B.3 En Route

#### Hazard Avoidance (Non-traffic hazards)

- E-1. Weather\*\*\**
- E-2. Turbulence*
- E-3. CFIT (Low altitude en route)\*\*\**

#### Self Separation and Spacing

- E-4. Collision Avoidance*
- E-5. Traffic Awareness*
- E-6. Visual Separation\*\*\**
- E-7. Station Keeping*

#### Emergency management

- E-8. Emergency Descent*
- E-9. Drift-Down/Emergency Descent\*\*\**
- E-10. En route Diversion / Loss-of-Control Recovery\*\*\**

#### Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management

- E-11. Mission Planning/Rehearsal\*\*\**
- E-12. Initial Climb/Descent*

#### Navigation

- E-13. Oceanic Aircraft Location - ADS-B*
- E-14. 4D Navigation, En route Optimization*
- E-15. Special Use Airspace / Airspace Depiction*

## **Descriptions and Notes**

### **Hazard Avoidance (Non-traffic hazards)**

#### *E-1 Weather\*\*\**

Three dimensional, pictorial depiction of radar and/or data-linked information of real-time (nowcast) and forecast weather. Weather information depicted should be prioritized by hazard type and include icing, mountain waves, jet stream awareness, clear air turbulence, etc.

#### *E-2 Turbulence*

There are basically two types of turbulence encountered by aircraft: 1) Wake turbulence is produced by aircraft in the form of counter rotating vortices trailing from the wingtips. These wakes can impose rolling moments exceeding the rolling control authority of the encountering aircraft. 2) Clear air turbulence is created by atmospheric conditions. This phenomenon has become a very serious operational factor to flight operations at all levels and especially to aircraft flying in excess of 15,000 feet. Turbulence generated by either of these types can damage aircraft components and equipment.

#### *E-3 CFIT (Low altitude en route)\*\*\**

In this application the crew would be given information in the synthetic/enhanced vision display that would improve low altitude en route flight in CFIT conditions. Information could be derived from a database designed to give an accurate depiction of the terrain.

It is possible that an accurate database would give the crew the means for viewing the challenging terrain. NASA along with NIMA utilized the shuttle to obtain a high-resolution digital topographic and image database of the Earth during a recent shuttle mission. It is expected that this information could be used to generate the database necessary for the SVS display in the flight deck. This would allow the crew to see the terrain, judge its location, and avoid possible hazards associated with the terrain during a low altitude en route flight.

Terrain, obstacle, and related flight information data is available from a variety of Government and private sector sources, such as, NIMA, ICAO, FAA, USGS, NGS, Jeppesen Sanderson, and a variety of other companies in the commercial mapping, satellite and aerial survey industries. The potential for using 3D and 4D imagery could also be included in the display information for the application.

### **Self Separation and Spacing**

#### *E-4 Collision Avoidance*

In this application synthetic/enhanced vision will address collision avoidance during the en route phase of flight. SVS would provide an image of the intruding aircraft and its position with respect to the own ship or non-intruding aircraft. The system would use a series of alerts to warn the crew of an impending collision.

### *E-5 Traffic Awareness*

In this application synthetic/enhanced vision would allow the crew to identify traffic through all the phases of flight. The system would provide an image or icon of an intruding or approaching aircraft. A system of alerts would be incorporated to warn the crew of the approaching aircraft. This would, possibly, give the crew automatic separation assurance. This application could also be applicable to the approach, ground operations, and departure phases of flight.

### *E-6 Visual Separation\*\*\**

This application involves using an SVS a separation tool in VMC to perform visual separation during a step climb in the en route phase. The airplane would be able to make a more fuel efficient gradual climb. A CDTI could provide accurate position information of surrounding traffic, and a spacing tool such as that employed for self separation might be used to provide separation during a climb. Wake vortex and weather information would be incorporated into the spacing function and perhaps depicted in a useful way. This guidance could be flown manually or with an auto pilot.

### *E-7 Station Keeping*

En route station keeping can benefit from the same technology that enables an SVS self separation capability. A synthetic vision display system would allow pilots to manage their in-trail separation in high or low visibility weather. Separation distances based on carrier class might be made more realistic using wake turbulence information. This information could be data linked to the cockpit. ADS-B state information from surrounding aircraft could be displayed in a format that allows management of separation from any chosen target aircraft. Separation guidance could be distance and / or time based with symbology appropriate to determine and improve performance. Guidance might be shown on the ND and be capable of being followed by the autopilot.

An SVS display system could provide a synthetic forward view with iconic representation of traffic enabling a visual separation capability in a low visibility environment.

## Emergency management

### *E-8 Emergency Descent (engine out, etc) Terrain Avoidance*

In instances of en route flight where aircraft are required to descend to lower altitudes than initially planned by the crew (usually due to engine failure), avoiding terrain can become an important safety issue. Typical reasons for such descents include engine trouble and other maintenance related considerations as well as avoiding turbulence. This is particularly a problem in flight over mountainous areas. Pilots' familiarity with the terrain and exact knowledge of the location of high terrain features such as hill and mountains are important issues related to descending safely to lower altitudes. Accurate knowledge of the position of the flight relative to extending terrain features is also a key issue.

A SVS would provide an accurate data-base-supported map of any region of flight and accurate positioning of the aircraft relative to terrain features. An application of this nature could also incorporate alerting of dangerous flight profiles based on navigation data and the terrain database. It could also, or alternately, be coupled with a TAWS.

#### *E-9 Drift-Down/Emergency Descent\*\*\**

Driftdown is the loss of capability to maintain altitude (loss of airspeed and lift) that may follow the complete or near-complete shutdown of one or more engines. The so-called driftdown altitude is a known characteristic at a given aircraft weight. It is a consequence of a powerplant problem, not just something that occurs on a continuous basis. The management of single-engine performance of multi-engine aircraft may become more difficult if the calculated sustainable single-engine flight altitude is lower than that required for safe terrain avoidance. Emergency descent is when an aircraft has a problem that requires an immediate descent to a lower altitude. The most typical reason for emergency descent is a loss of pressurization where the aircraft has to descend to an altitude (usually below 10,000 feet) rapidly. SVS technology has the potential for use in displaying calculated profiles for safe descent in these situations where a failure has occurred. In an application, algorithms supported by an appropriate terrain database would determine a safe descent profile.

#### *E-10 En route Diversion / Loss-of-Control Recovery\*\*\**

During an emergency depressurization or engine loss, this system enables the flight crew to “be ahead of the airplane” and perform segmented or full mission rehearsals during the diversion or loss-of-control situation. Through a datalink, controllers and airline operations personnel could be intuitively (or visually) aware of the flying situation and hazards and better consult with and advise the aircrew in real-time decision making.

### Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management

#### *E-11 Mission Planning/Rehearsal\*\*\**

This system enables the flight crew to “be ahead of the airplane” and perform segmented or full mission rehearsals. This system is not constrained to flight phase and could be implemented even outside the airplane in the airfield/airline operations center for pre-flight use by the mission crew.

#### *E-12 In-trail Climb/Descent*

En route altitude changes could benefit from a self-separation tool using the enhanced precision and frequency of ADS-B information displayed on a CDTI-like navigation display. Climbs and descents could benefit from wake turbulence information factored into separation algorithms. In low visibility conditions traffic and wake turbulence information might be displayed in a forward-view synthetic vision display.

## Navigation

### *E-13 Oceanic Aircraft Location – ADS-B*

This application involves the use of SVS technology to display location of the own airplane and proximate traffic to the pilot. ADS-B will provide the location of traffic operating in the area. This SVS technology could also be used for en trail climbs and descent. It may also have application in wake vortex offset in transoceanic operations.

### *E-14 4D Navigation, En route Optimization*

4D navigation is important to airlines in achieving on-time operation goals, specifically in getting their flights into the terminal area so that they can land and meet connection requirements. A part of this consideration is to be able to use efficient routes that save fuel in getting to destinations. This capability may become increasingly important as methodology such as paired staggered approaches are implemented in terminal area approach environments.

### *E-15 Special-Use Airspace\* / Airspace Depiction*

Special use airspace is airspace where activities may be confined because of the nature of activity in that airspace or on the ground. Due to these activities certain limitations may be imposed on the use of this airspace. Airspace depiction would outline areas where air traffic control authorization would be required to fly into that area. This application can be used for all phases of flight.

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\* Special Use Airspace includes: Alert Areas, Controlled Firing Areas, Military Operating Areas, Prohibited Areas, Restricted Areas, and Warning Areas.

## B.4 Ground Operations

### Hazard Avoidance (Non-traffic hazards)

- G-1. Obstacle Avoidance
- G-2. Aircraft Clearance Awareness\*\*\*
- G-3. Deicing Station
- G-4. Gates

### Self Separation and Spacing

- G-5. Runway Incursion\*\*\*
- G-6. Runway Incursion Detection and Accident Prevention\*\*\*

### Emergency management

- G-7. RTO
- G-8. SVS on Emergency Vehicles

### Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management

- G-9. Mission Rehearsal\*\*\*
- G-10. Ground Equipage for CAT IIIc\*\*\*
- G-11. Rollout/Runway Based Cues
- G-12. Turn Off and Hold Short
- G-13. Speed Awareness
- G-14. Language Barriers

### Navigation

- G-15. Taxi Guidance in Low Visibility
- G-16. Precision Control
- G-17. High Visibility Taxi Guidance
- G-18. Taxiway Excursions

## **Descriptions and Notes**

### Hazard Avoidance (Non-traffic hazards)

#### *G-1 Obstacle Avoidance*

In this application, the synthetic/enhanced vision display could be used to detect birds or other unknown objects in the approach airspace or runway area. Some type of sensing device would be needed since a database would not show the bird, objects, or obstacles on the runway. It would aide in detecting construction areas, ground vehicles, and some wingtip awareness.

The capability will also have applicability in the approach and departure phases of flight. This application could also be used with ground vehicles such as fire trucks, etc.

#### *G-2 Aircraft Clearance Awareness\*\*\**

This means providing an intuitive depiction of the current aircraft clearance – with guidance as necessary. The pilot and co-pilot could use such a system to steer/taxi the aircraft in all weather conditions.

#### *G-3 Deicing Station Guidance*

This application involves the issue of delay between the time an airplane has been serviced by deicing equipment and the time it takes off. This time delay is affected by the airport traffic, clearances, weather, ground visibility, and the ability to efficiently taxi to the correct runway. An SVS system depicting a synthetic view of the airport runways, and traffic, could provide optimal guidance to the correct runway and deicing stations. The ability to navigate in low visibility conditions as well as is possible in clear conditions along with the guidance to the correct runway could reduce the rate of multiple deicings. Guidance might consist of a runway map with cues using the plane's position information. Guidance might also be more tactical in appearance using a flight director like system imposed on a synthetic forward view.

#### *G-4 Gates (movement in the vicinity of)*

At some airports the area around the gate is in an airport non-movement area. That is, all movement to and from the gate is at the pilot's discretion and does not come under air traffic control jurisdiction. This SVS application involves providing situation awareness information such as a view of the gate relative to the position of the airplane so that the pilot can align and park at the gate and operate more safely in the vicinity of the gate.

### Self Separation and Spacing

*G-5 & G-6 Runway Incursions\*\*\** See Approach application A-11.

## Emergency management

### *G-7 RTO*

This application utilizes synthetic vision technology to assist the pilot in takeoffs by making rejected-takeoff information more conveniently available to him or her. This will be accomplished by integrating such information into the primary visual information being used. It is envisioned that an SVS-based PFD or HUD would incorporate RTO information.

The information would be of the type conventionally displayed on the PFD in current operations or it would use more advanced formats of the nature developed in the NASA ROTO program. The information would be intended to provide improved situation awareness of runway remaining, and other parameters related to completing the takeoff. In addition to showing runway remaining, the information presented could include stopping distance calculations and incorporate related advisory displays.

### *G-8 SVS on Emergency Vehicles*

In emergency situations rapid response of ground vehicles is important. Vehicle guidance showing the most direct safe route to an accident would save time. This could be depicted on an airport map HDD. In conditions of limited visibility the guidance might additionally be displayed as tactical cues on a HUD with a synthetic image of the forward view of the airport. Enhanced vision sensors might provide position information of dynamic obstacles.

## Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management

### *G-9 Mission Rehearsal\*\*\**

The capability enabled by SVS will provide the pilots with the ability to practice missions prior to having to perform them in flight. This system enables the flight crew to “be ahead of the airplane” and perform segmented or full mission rehearsals. This system could be implemented even outside the airplane (in the airfield/airline operations center for pre-flight use by the mission crew).

### *G-10 Ground Equipage for CAT IIIc\*\*\**

There are numerous ground components that support any ILS category approach. The more adverse condition or restriction to visibility the more components are required. For CAT III operation an approach light system, touchdown and centerline light system, runway light system, taxiway lead off light system and RVR system are necessary.

Only selected airports have CAT III approach capability. This is due mainly to lack of ground equipment. Consequently, when the approach minimums are lower than the highest category approach at that airport, approaches are suspended.

When an approach is conducted to an airport with CAT III capability, the visibility is usually extremely low causing greater caution when exiting a runway; consequently,

traffic flow is reduced. With SVS, traffic could exit the runway quicker allowing for a greater arrival flow to that airport. Also, the ground equipment would not be critical to display the approach to the runway, runway outline and centerline, and lights leading to the taxiway.

#### *G-11 Rollout/Runway Based Cues*

After touch down during a landing operation, the next task of the pilot is to exit the runway. This task includes lowering the speed of the aircraft and turning onto an exit ramp. Only after that operation has been successfully completed does the runway become available for the next takeoff or landing. Conducting the rollout and turnoff safely and efficiently has both safety and operational implications.

In this application, the pilots will be provided an accurate view of the location of the runway, its edges, and the turnoff ramp locations relative to the location of the own airplane. It is envisioned that the view will be presented as a dynamic graphic illustration displayed on an instrument-panel-mounted display surface (CRT or flat panel display) or presented in a HUD. The location of the own airplane would be determined from DGPS technology and the location of the relevant airport features from a database.

NASA LaRC has conducted research in this technology (Ref 2).

#### *G-12 Turn Off and Hold Short\*\*\**

Runway markings to direct turnoff to a taxiway is displayed as a solid yellow line turning into the taxiway. Runway hold short markings are four yellow lines, two solids and two dashed, perpendicular to the taxiway or runway where the hold short is to occur.

#### *G-13 Speed Awareness*

After landing, an airplane must be brought under control in order to safely turn off onto a runway exit. Exiting sooner decreases ROT. A pilot's ability to control speed to a level slow enough to safely turn off onto a given exit could be aided by a display showing the predicted position and speed of the aircraft given the current thrust settings and braking condition. Having such a display reflect changes in thrust and braking dynamically would give the pilot feedback measuring the effectiveness of control inputs. The position and speed information might be superimposed on a synthetic runway display. Speed guidance to the "next" exit might be provided in addition.

#### *G-14 Language Barriers (similar to ground operation application G-2)*

This means providing an intuitive depiction of the current aircraft clearance – with guidance as necessary. The pilot and co-pilot could use such a system to steer/taxi the aircraft in all weather conditions.

## Navigation

### *G-15 Taxi Guidance in Low Visibility*

SVS can support low-visibility taxi operations by providing turn, hold-short, ATC clearance, and pathway guidance and projection to the flight crew.

### *G-16 Precision Control*

This application addresses the problem of enabling aircraft to operate on the airport surface when the out-of-the-window view is hampered by fog or precipitation. In many situations, even if aircraft could land they would be unable to taxi safely to the gate. Also, because of poor visibility, occasionally, aircraft are unable to taxi safely from the gate to the runway.

This application incorporates guidance information made available to the pilots to operate on the surface of airports when the visibility is low. The operations involved include taxi between the gate and the runway. These are low speed operations where surface navigation and obstacle clearance are of primary importance to achieve operational and safety benefits. LVLASO is the primary NASA research addressing this application. Its information is displayed on a monitor mounted in the forward flight deck instrument display panel. It incorporates a plan-view illustration of the airport layout showing the runways, taxiways, structures and fixed equipment that are factors in navigating and safety, the position of the own airplane and other surface traffic. This concept includes the use of DGPS for accurate positioning and ADS-B to enable an aircraft to broadcast its own position and receive the broadcast position of other traffic operating on the surface. The concept would include having such positioning equipment onboard both aircraft and service vehicles operating on the surface.

### *G-17 High Visibility Taxi Guidance*

SVS can enhance what the pilot sees now in good (high) visibility with an intuitive depiction of turn, hold-short, ATC clearance, and pathway guidance and projection to the flight crew.

### *G-18 Taxiway Excursions (related to G-16 Precision Control)*

SVS can prevent excursions from the pavement in low and normal visibility by alerting flight crews to potential taxi errors.

## **Appendix C – Scenario of Gate and Ramp Area Operations**

To fully appreciate the complexity of operations in the immediate gate and ramp\* areas, the following scenario is offered. Many of the specifics are of course airport, aircraft, and airline dependent.

### *Aircraft Servicing*

An aircraft, operated by a major U.S. airline, is parked at a gate in a large domestic airport. As is customary in the industry, the airline employs the "bank" concept at this hub. That is, large numbers of aircraft arrive, discharge passengers, are serviced, board passengers, and depart within a total time span of about an hour and a half. Nearly all of the more than 50 gates available at major terminals are involved. It is not unusual for a scheduled flight to arrive at a gate within five minutes of the scheduled departure of the previous aircraft.

Because of the short turn-around time, most normally required service personnel, equipment, and parts (common avionics, built-up wheels and tires, and cabin items such as seat covers and coffee makers) are available in the ground level of the gate area. Service lanes connect the gates and provide access to the lower baggage facility, lavatory service, and other operations. Visibility as low as 150 feet should not significantly impact normal servicing of the aircraft by these support functions. Experience has shown that in conditions of very poor airport visibility, the gate area enjoys noticeably better visibility. That is probably due to heating from the many surface vehicles and additional high-intensity lighting.

Other support is located some distance from the gate area. Emergency equipment, although rarely required, is located at one or more facilities near the runways. Food Service is often contracted, and will be located in a central kitchen apart from the gate area. Fueling is normally accomplished by connecting to an underground system, but at some airports, fuel trucks are still used and must be filled at a remote tank farm. Each of these services is vulnerable to weather or surface-condition delays.

Many airlines deice aircraft by means of mobile deicing rigs. Deicing fluid is often replenished at a remote location, typically the airline's maintenance hangar. Conditions cited above that impede vehicles would also impact deicing trucks.

### *Aircraft Pushback and Engine Start*

Most operators use a pushback procedure where a tractor (tug) pushes the aircraft away from the gate and positions it on the ramp area or taxiway ready to proceed under its own power. In some cases, particularly at very small stations, the aircraft will taxi away from the gate under its own power. Some airplanes (B-727, DC-9, MD-80/B-717) are capable of using their own reverse thrust to power-back from a gate.

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\* Ramp – Area of an airport that is controlled by an airline. Includes gate operations for several gates.

The airline Maintenance Lead has authority over the aircraft and pushback until the tow bar is disconnected from the nose wheel and a salute exchanged between the Lead and the aircraft Captain. At that moment, the Captain is in command of the airplane and makes all decisions regarding operation.

An airline Ramp Controller manages vehicle and aircraft movement to a physical point where ATC assumes responsibility for surface operations. At large airports, a team manages these functions, with each individual having specific responsibilities. Often, a supervisor will oversee the operation from a small ramp tower. The Maintenance Lead in charge of pushback of a specific aircraft requests clearance via radio from the Ramp Controller. The Ramp Controller monitors aircraft positions within his jurisdiction by means of strategically placed video cameras at each gate. When the clearance is received, the Lead advises the cockpit to "...release brakes." This is acknowledged by the flight deck, and the aircraft is pushed onto the adjacent taxiway. Some airplanes start engines prior to or during pushback while others do not start engines until the tug is disconnected from the aircraft. Until the tow bar is released and salutes exchanged, an SVS would be of little value to the aircraft in this type of scenario.

Although the scenario represents operations at large hub-type airports, feeder airports could also derive significant benefits from SVS applications. For example, RTCA DO-242 alludes to significant savings if the two to three 'marshallers' required in some very low visibility pushback operations could be reduced to one with appropriate on-board depiction of other aircraft with respect to own-ship. Visibility in the range of 150 to 600 ft could benefit from an integrated SVS system, one that includes essential ground vehicles in the plan. Any system that has a goal of VMC-equivalent operation in specified visibility conditions must provide a solution for ground vehicles operating outside of the immediate gate area. The crash, fire, and rescue (CFR) equipment and servicing vehicles need to operate safely and efficiently. The FAA recommended EV-type of equipment for such ground equipment in an advisory circular Driver's Enhanced Vision System (DEVS), FAA AC-150/5210-19, December 1996.

## Appendix D – Restrictions and Procedures for Departure

### *Single Runway Departures*

The following are typical VMC restrictions and procedures in single-runway departure environments:<sup>\*</sup>

1. There are standard take-off minimums for commercial air carrier operators applicable to the majority of runways in the country. For a particular runway, the minimum may be standard or as otherwise specified for the runway in the U.S. Terminal Procedures publication. When the minimums for a particular runway are specified, they supersede the standard requirements, are generally more stringent, and will typically include a ceiling. In addition, they frequently include requirements to clear terrain features or other obstacles.
2. ATC will clear the flight for takeoff, ensuring that there is no other traffic cleared to that runway and no other instrument traffic cleared to the same airspace.
3. The tower controller is normally expected to see the runway, or at least verify, that the runway is clear of traffic before a take-off clearance is given. Airport Surface Detection Equipment (ASDE) and CPDLC can assist the controller in supporting low-visibility ground operations leading up to the departure.

### *Parallel Runway Departures*

In parallel departure operations, either the tower controller or the pilot will have responsibility for separation. The pilot may be given the responsibility by way of the controller ascertaining that the pilot can see any parallel traffic and will accept the responsibility (visual separation). When the tower controller retains the responsibility, normal procedural separation will be imposed. One aircraft will be vectored to an appropriate diverging course, or a miles-in-trail spacing rule will be applied. The tower controller also has the option to visually separate the aircraft and not apply standard separation for as long as the aircraft remain in the tower's airspace and can be seen.

The pilot must fly the expected departure route. They will most often be cleared to fly a standard instrument departure procedure (SID) or some other course at the controller's direction.

### *Parallel Departures in VMC (Parallel runways spaced 2500 feet - 4300 feet)*

Parallel departures can be accomplished in VMC with the following restrictions for runways spaced greater than 2500 feet but less than 4300 feet.

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<sup>\*</sup> Where there is no conflict with parallel departures closer than 4300 feet laterally or departures from a crossing runway.

1. Aircraft may be cleared to depart simultaneously if responsibility for separation is handed off to one or both of the flights (visual separation).
2. The tower controller will normally vector the departing aircraft onto appropriate diverging courses immediately after takeoff.
3. The tower controller has the option to assume visual separation responsibility and not put the aircraft on diverging courses. However, some form of standard separation must be applied before the aircraft departs tower airspace or the tower controller loses visual contact with the aircraft.

*Parallel Departures in VMC on closely-spaced (less than 2500 ft) runways*

There are conditions in departure operations that enable aircraft to depart airports in VMC when the runway separation is closer than 2500 feet. When those conditions cannot be met because of visibility that is below minimums, restrictions are placed on the departure operations that reduce the number of departures.

1. The primary difference between this case and the 2500 to 4300-foot case is that now the controller has to be concerned with wake turbulence between the flights on adjacent parallels.
2. The controller will vector the departing flight to diverging paths immediately after takeoff, or apply wake turbulence separation standards. (Aside: Depiction of wake turbulence in an SVS display could provide the operational flexibility of transferring wake avoidance from ATC to the pilot.)

*Parallel departures in IMC on runways laterally spaced 2500 feet or more.*

1. Wake turbulence separation is not required between traffic on adjacent parallels.
2. ATC will procedurally turn one of the parallel flights to an appropriate divergent heading immediately after takeoff.
3. ATC maintains separation responsibility in IMC since the pilot will not be able to see the traffic.

*Parallel Departures in IMC closer than 2500 feet*

In IMC conditions, when parallel runways are spaced closer than 2500 feet, the runways are treated as a single runway operation. Aircraft cannot be cleared for takeoff from either runway until the required separation is established.

## **Appendix E – Operational Benefit Analysis**

The discussion in this section is adapted from a NASA sponsored operational benefits study conducted by the Logistics Management Institute (LMI). See Reference 5.

This is a review of the results of the analysis and their implications for the synthetic vision system Concept of Operations.

### Review of results

The benefits from SVS and related technologies can be included in the following categories that are listed in the order of increasing impact:

- reduced runway occupancy time in low visibility
- reduced departure minimums
- reduced arrival minimums
- converging and circling arrivals: use of dual and triple runway configurations in IFR conditions
- reduced inter-arrival separations
- independent operations on closely-spaced parallel runways

In addition to these, the ability of SVS to support VFR tempo low visibility ground operations, while not directly affecting airport capacity, is vital to realizing other benefits.

### Reduced Runway Occupancy Time

Runway occupancy times are estimated to increase 20% with low visibility, wet conditions. The NASA Roll-Out and Turn-Off technologies that are included with SV2 and SV3 [levels of implementation (see Table E-2)] are assumed to eliminate the 20% penalty. With SV2, ROT reductions will have no impact in low visibility conditions because arrival aircraft separations are determined by miles-in-trail (MIT) requirements. With SV3, the MIT separations are reduced and the ROT reductions provide some benefit. Delay model results for SV3, with and without the ROT reduction, indicate that ROT reduction has a relatively small effect on the benefits from reduced miles-in-trail separations.

### Reduced Departure Minimums

Head-up guidance systems, enhanced vision systems, and SVS will all allow reduction of the 700-foot minimum departure visibility. Aircraft with head-up guidance systems are already authorized to depart with 300-foot visibility. The minimum is based on the ability of the aircrew to see the runway centerline and to safely control and stop the aircraft if an engine fails. The model results indicate that the potential benefit from the reduced departure minimum ranges from \$3M per year at Minneapolis to \$51M per year at Seattle.

## Reduced Arrival Minimums

The results for the ten airports indicate that reducing arrival minimums for the current IFR runway configurations has only marginal impact on delay. This result is not unexpected. At the airports we modeled, significant resources have been committed to low visibility landing capability. Current capabilities are designed to meet the vast majority of expected conditions. Eight of the ten airports have CAT IIIb runways including two with 300 ft RVR capability.

## Converging and Circling Approaches

We predict very large benefits at ORD and EWR, and significant benefits at MSP and DFW for the use, in IFR conditions, of high-capacity multiple-runway configurations that are now restricted to VFR. Use of these configurations requires the ability to safely fly converging and/or circling approaches in IFR. The benefits also require that the additional runways have IFR CAT III arrival minimums. All the SVS technologies are assumed to allow converging and circling approaches in IFR. SV1 supports the approaches down to 600 ft RVR, while SV2 and SV3 extend down to 300 ft RVR.

## Reduced Inter-arrival Separations

We predict significant benefits at all airports for the reductions in IFR aircraft separations included in SV3. The benefits are very large for ATL and LAX, where runway capacity is very congested, and there is no way to add capacity other than building new runways.

## Independent Arrivals on Closely Spaced Parallel Runways

The NASA AILS technology enables independent approaches to parallel runways with centerline spacing of at least 2500 feet. We assume SV3 includes the AILS capability and thus allows independent operations on closely spaced parallel runways at DTW, MSP, SEA, and JFK. Since SV3 also includes reduced separations (RS) we ran cases with and without RS and AILS to determine which technologies were responsible for SV3 benefits. The results are shown in Table E-1. The first row shows that combined RS and AILS reduce delays below SV2 levels by 14% to 19%. We see from the data in the second and third rows that the results for RS and AILS are not additive; the benefits of the sum is less than the sum of the individual benefits. Except for JFK, a significant fraction of the benefits can be had with either RS or AILS independently. At JFK, only RS provides a significant benefit.\*

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\* At JFK, AILS improves the capacity of the Parallel 4s and Parallel 22s configurations, but, due to ground operations limitations, their capacities are still less than that of the Parallel 31s configuration. Since the model searches for the highest capacity usable configuration, the Parallel 31s continue to dominate operations and AILS has minimal impact.

**Table E-1. Relative Benefits of Reduced Separations and Independent Arrivals on Closely Spaced Parallel Runways**

	JFK	SEA	MSP	DTW
SV3 savings relative to SV2: AILS + RS	0.14	0.17	0.17	0.19
Fraction of SV3 savings due to AILS without RS:	0.12	0.68	0.70	0.74
Fraction of SV3 savings due to RS without AILS:	0.91	0.51	0.39	0.51

#### Low Visibility Taxi

The arrival capacity benefits of SVS technologies cannot be realized if the landing aircraft cannot taxi expeditiously in low visibility conditions. The NASA Taxiway Navigation and Situational Awareness System is the enabling technology that allows VFR tempo ground operations in IMC. T-NASA is essentially the ground operations analog to airborne SVS; the aircrew navigates using synthetic representations of the runways, taxiways, and gates. T-NASA technology is designed to allow VFR tempo ground operations with visibility as low as 300 feet. SV1 is assumed not to have T-NASA and, therefore, is effectively limited to 600-foot visibility operations. SV2 and SV3 include full T-NASA capability.

#### Hardware Considerations

The technology levels in our analysis are based on capability and are not tied firmly to hardware. Specific hardware implementations were, in fact, hypothesized and discussed during the task. In the end, it was decided that we cannot tell, prior to testing, the specific hardware necessary to provide the levels of capability analyzed, and that, at this time, it is more accurate to refer to capabilities rather than hardware. That being said, it is useful for test planning purposes (and for future cost benefit analyses) to consider the *potential* hardware implementations that correspond to the technology levels.

Table E-2 contains a hypothetical list of hardware for each technology implementation.

**Table E-2. Hypothetical Equipment Requirements**

Technology	Aircraft Equipment	Ground Equipment
Baseline	LAAS receiver EGPWS TCAS CDTI data radio LNAV VNAV VSAD Autoland capable autopilot FMS	LAAS ground equipment CDTI data radio ASDE-3
BLH	Baseline + Head-up Display (HUD)*	Baseline
EVS	Baseline + HUD* + Enhanced Vision System	Baseline
SV1	Baseline + ADS-B Database Head-down Display	Baseline
SV2	Baseline + ADS-B Database Head-down Display HUD	Baseline
SV3	Baseline + ADS-B Database Head-down Display HUD Supplemental Sensor	Baseline + Low Visibility Taxi Equipment AMASS multi-lateration or vehicle GPS low visibility emergency vehicle sensor

\* The head-up display is assumed to include navigation information such as that found in the Flight Dynamics, Inc. Head-Up Guidance System 

## CONOPS Implications

Based on the predicted benefits and our assumptions about hypothetical hardware we can now address recommendations for the NASA SVS Concept of Operations document. The results indicate that the ability to conduct circling and converging approaches will provide major benefits at two key airports (Chicago, Newark). Reduced arrival separations are essential at two other key airports (Atlanta, Los Angeles). The remainder of the capabilities provide significant, but lesser, benefits. The ability to conduct low visibility ground operations at normal visual tempo is an essential enabling capability for all benefits. The CONOPS should include requirements that support these capabilities. We recommend the following demonstrations [tests, simulations, analyses] be included in SVS testing.

- The ability to safely conduct converging and circling operations in IFR CAT IIIb conditions.
- The ability for an aircrew to autonomously follow and hold position behind a leading aircraft in the traffic pattern and on final approach. Determine distance from the threshold of the last position adjustment.
- The ability to conduct ground operations at VFR tempos [operations rates] with visibility as low as 300 feet.
- As a minimum, the ability to conduct arrival and departure operations under conditions of zero ceiling and 300 ft RVR with a goal of demonstrating operations at zero RVR.
- Determination of the minimum operational hardware requirements for each of the capabilities above. Specifically,
  - whether a head-up display is technically required for each capability.
  - the minimum hardware suite necessary to provide FAA required system performance and reliability.

## Appendix F – Issues

After the February 2000 SVS Concept of Operations workshop at LaRC, a draft of the resulting CONOPS document was released to participants and other stakeholders for comment. Many of the responses were incorporated into the body of the document. The remaining comments describe open issues related to the design and use of the system that will require further investigation as the SVS is developed. Those comments, questions, and issues are grouped into the following classes:

- Benefits, Risks, Cost - BRC
- Displays - D
- Human Factors - HF
- Procedures - P
- Simulation - S
- Sensors and Databases - SD

The issues are described in table F-1 grouped by the above classes and enumerated for future reference. Abbreviations enclosed in parentheses indicate alternate or secondary classifications.

**Table F-1. CONOPS Issues**

<b>Benefits, Risks, Cost</b>	
BRC-1	The text indicates that a cost-benefits analysis has been performed. Have specific cost targets been established? If so, has the analysis showed that the SVS will indeed be cost effective for programs like AGATE? Such an analysis is basic to making a viable SVS program.
BRC-2	If the airplane is equipped and approved with various systems, for example if the airplane is approved for CAT III approaches, the addition of SVS will be much less costly than in airplanes only approved for CAT I approaches. An airplane only approved for CAT I approach will need additional power sources, associated equipment, more reliable flight controls, etc. [What are the cost implications for SVS implementations in existing equipment (e.g., CAT I vs. CAT III equipment)?]
BRC-3	Many of the risks that we have identified in our risk assessments of ADS-B, Capstone, and Ohio Valley OpEval 2 seem to be applicable to SVS. These items include dropped tracks, track skipping, hazardous and misleading information, training, etc. These issues do not seem to be addressed in the CONOPS. [What are the risk factors associated with SVS implementation? Examples are dropped tracks, track skipping, hazardous and misleading information, training, self-separation, database management.]
BRC-4	There needs to be careful consideration as to whether this approach is the optimal solution. It is unclear as to whether the SVS concept is driving the requirement or that SVS is the correct solution to meet NAS needs.

<b>Displays</b>	
D-1 (HF)	Display Clutter -- Given the number of possible tools that can be displayed on the SVS, clutter would seem to be likely if several are displayed at once. Potentially, a pilot could simultaneously be using the wake turbulence, terrain, parallel approach, weather, LAHSO, runway incursion, missed approach, path accuracy and VASI tools all at once.
D-2	The display of synthetic data that is usable by the pilot was not identified very clearly as a specific issue that needs addressing. There have been a lot of attempts to provide this type of data on HUD and HDD. The cues particularly of HDD have not been acceptable on a lot of displays evaluated in the past. It is suggested that this aspect may need to be identified as an issue. Can the cues presented to the pilot on SVS be made sufficient to provide the ability to safely fly the SVS displays?
D-3	How, exactly, pilots control what is displayed on each display and when.
D-4	How, exactly, head-up and head-down displays are integrated.
D-5	How, exactly, sensor and artificial imagery are integrated.
D-6	How, exactly, pilots are guided back to the path or some other desired point after leaving a pathway-in-the-sky to avoid a displayed hazard.
D-7	How, exactly, pathways in the sky will be flown and with what precision (e.g., What's the narrowest pathway we need or should expect pilots to be able to fly? Will this depend on wind, visibility, other traffic, etc.? Will the pathway help the pilot compensate for these factors (by showing correct bank and/or crab angle for a given crosswind, for example)?
D-8	Enhanced Flight Information – The frequent reference to “Tunnel in the Sky” tends to imply one solution to the display of the intended path. For most applications discrete “Waypoints in the Sky” would serve to accomplish the same thing, perhaps with less clutter. Waypoints could be color coded as to Active, etc. for correlation with the Legs page of the FMC, VSAD, and the ND.
D-9	These tunnels might only be useful from the Initial or Final Approach Fix inbound, and then only if a significant turn is associated with the later stages of the approach.
D-10	In today’s world of approaches, the need for a tunnel in the sky might be the exception rather than the rule.
D-11	For parallel departures as well, depiction of a tunnel or corridor has not been found to be useful (previous Boeing and NASA workshops and studies) on departure, when three- dimensional geographic constraints do not exist, as is typical during constant airspeed, constant power setting climb.
D-12	The use of pathways in the sky for departure may not be practical. ATC constraints and variations in the methods used for climb make it unlikely that a path would be followed, and during engine out operations, the path would have to change and would be a fall-out of holding the appropriate airspeed and setting the appropriate thrust.
D-13	Required ground tracks and crossing restrictions on departure could perhaps be easier to follow with some added SVS visual aides, such as discrete waypoints in the sky.

<b>Displays</b>	
D-14	<p>(Pathway-in-the-Sky): The presentation of a "pathway-in-the-sky" requires some method for the generation of the relevant data. Basically, there are two approaches:</p> <p>A. Generate all possible paths off-line and upload them like any other navigation database; This approach leads to less problems in the certification process but limits the crew's free-flight navigation capabilities to pre-determined flight path solutions, i.e. it can't take into account dynamic changes required by ATC/weather, etc.</p> <p>B. Implement an on-line component that facilitates the real-time generation of paths during flight ("On-board planning/re-planning");</p> <p>This approach provides the crew with a very sophisticated way of replanning flights onboard taking into account actual changes in the flight planned profile. However, the certification aspects of such a component will be very difficult, since its functionality contributes to the derivation of primary flight guidance information.</p> <p>It is not clear from the document which approach is envisioned for the CaB SVS. It would help in the clarification of the CaB SVS concept if some statement could be made as to what extent an on-board re-planning capability is part of the envisioned operational concept.</p> <p>[How will pathway-in-the-sky routes (data) be generated and interfaced or communicated to SVS?]</p>
D-15	<p>For a pathway in the sky depiction, what is the path when a radar vector or heading clearance is given? When the airplane is not facing the path, the path is not visible in the display, what will be provided to guide the pilot? What about the vertical axis, when there is not really a discrete vertical path, just a climb according to an airspeed schedule?</p>
D-16	<p>Making the SVS display compatible and consistent with our traditional FMC philosophy is important.</p>
D-17 (HF)	<p>Maintaining "visual contact (virtually)" (i. e., operating off parallel departure runways) could be a problem if the FOV is limited to that available from a PFD. This needs to be assessed. A Head Mounted Display (HMD) could solve this problem. An HMD would easier to retrofit. Research should include these devices, even though they now might appear to be a rather unconventional solution.</p>
D-18 (HF)	<p>I would add information saturation, and display clutter to this list. I'd also add cognitive switching as an issue - how do we prevent a pilot from getting distracted by or overly focused on symbolic information, at the expense of other scene elements, or the visual scene?</p> <p>[Information Saturation – What are the effects of displaying an overabundance of information? Display Clutter – How will it be controlled?]</p> <p>Fixation - How do we prevent a pilot from getting distracted by or overly focused on symbolic information, at the expense of other scene elements, or the visual scene?</p>
D-19 (HF)	<p>The general objective of replicating VMC safety and operational benefits in IMC is an important theme throughout this document. Yet the system concepts described in the document are largely aimed at the forward field of view. A key capability of a system that meets the stated objective is that it provides equivalency to the pilot compartment view required by the Federal Aviation Regulations (FAR).</p> <p>[What pilot compartment field-of-view requirements must be satisfied by SVS?]</p>
D-20 (HF)	<p>While it is premature for me to comment specifically on system characteristics, I will point out the degree of flexibility the pilot will have to control display formats, layouts, clutter (or information content), adds to the requirements to demonstrate that each selectable combination be demonstrated and evaluated for certification. The more deterministic the choices are, the less burden there will be on the certification applicant. As the cockpit technologists know, unlimited variations can have unforeseen effects on pilot scanning and awareness, particularly of anomalous conditions. [What are the effects on pilot scanning and awareness of flexibility for the pilot to control display formats, layouts, clutter (or information content)?]</p>

<b>Displays</b>	
D-21	Certainly the field of view parameter is key in the SVS program. It is not clear, however, what SVS fields of view are presumed for such operations as parallel departures and landings, circling approaches, and so forth. It seems that these require a peripheral (lateral) field of view, but the emphasis on intuitive or “virtual vision” is in the forward field of view. To provide VMC levels of safety and efficiency, the standards of pilot-compartment view must be met, particularly as they would contribute to VMC operations.
D-22 (HF)	The use of a ‘virtual-visual” display for traffic separation sounds easier than it probably is. Unlike the design of the eXternal Vision system (XVS) conceived for the High Speed Research program, which was conformal in scale and orientation, the SVS displays are located on the instrument panel and are not sized for conformal presentations. Will the flight crew be able to judge traffic separation on a “minified” (opposite of magnified) display?
D-23	The pilot should have the capability to select various formats for displaying SVS functions for the phases of flight and desired operation, but there should be a direct standard display format available that the pilot can select. Direct switch activation should be available without going through a series of menus in case the pilot is confused or the pilot desires rapid access in case of an emergency.
D-24	Overlaid of TAWS or EGPWS information with the SVS radar data on the terrain display of terrain imagery will need special design features since the TAWS and GPS terrain data may not be as accurate as the SVS radar data; therefore, the images will not coincide on the display.
D-25 (SD)	Sensor Displays: “Various sensor images can be overlaid, processed, integrated or fused.” ... This will be extremely difficult.
D-26 (HF)	The [RI] warning to the crew should have two components. First the EICAS warning that an incursion is eminent, followed by an SVS depiction of an aircraft (e. g., highlighted for its attention getting value) moving onto the active runway.

<b>Human Factors</b>	
HF-1 (BRC)	The increase in accidents in low visibility conditions is cited here. Use of SVS will require additional pilot workload and awareness of traffic. It seems possible that diverting pilot attention from normal duties may have an unforeseen, negative impact on safety.
HF-2	Pilot human factors study would have to validate an acceptable increase in pilot workload using SVS and acceptable system readability and reliability.
HF-3	Extensive Human Factors work will need to show acceptable controller and pilot workload while using procedures and equipment associated with SVS.
HF-4 (BRC)	The problems of pilot error and mistakes have been shown to be contributory factors for most accidents and incidents in all categories of aircraft operations. I was surprised that human factors was not identified as a primary issue in the SVS program. Pilot error has been identified by the FAA as a major contributor to most accidents. Can an SVS be defined that will allow the pilot to make correct decisions every time even under failure conditions? How will workload be addressed under the SVS scenario? (Comment: Since SVS will present data to the pilot as valid data, care must be taken to ensure NO misleading data is presented whether due to failures or to accuracy.)
HF-5	Crew fatigue has been identified as a factor in accidents such as CFIT. It is not clear that EGPWS will alleviate this problem. Crew fatigue has been a cause of CFIT accidents that likely would not have been prevented by EGPWS, TAWS or similar technology systems. Investigation will be made to determine the approaches that will address this problem.

<b>Human Factors</b>	
HF-6 (D)	Another objective of the program should be to develop a structured logic for cockpit information placement requirements - - HDD, HUD or HMD by flight phase. For example: cueing information up, situation awareness information down, or some other general rule. It would be tragic if information required in the cockpit is placed in the wrong location and actually inhibits safety. [What is the logic and requirements for information placement (HDD, HUD, HMD) by flight phase? For example, cueing information up, situation awareness information down, or some other general rule.]
HF-7 (BRC)	The proposal identified a solution to an aviation need. The SVS need appears justified, but recommend including reviewing specific user requirements. Will SVS meet the need of the user? Who is the user? This survey would identify airline requirements, match these requirements to existing technology, and to leverage Department of Defense sensor programs. The SVS concept may or may not be successful, but there needs to be careful consideration as to whether this approach is the optimal solution. It is unclear as to whether the SVS concept is driving the requirement or that SVS is the correct solution to meet NAS needs. Lastly, the proposal needs to integrate human performance considerations associated with using SVS in mentioned applications. The proposal is a concept of operations, but there are a number of human factors issues that must be considered at this stage to determine whether this technology is worth pursuing. Listed below are few human factors issues to consider:
HF-8	Does synthetic vision enhance pilot's situational awareness compared to out-of-the-window viewing or to enhanced vision under no or low visibility conditions? Specific performance measures include: Time to respond to traffic on the runway, time to determine bad flight path, time to reorient aircraft position during synthetic vision outage, time to respond to approaching traffic, recovery performance from unusual attitude, time to respond to ATC's flight path change, time to respond to TCAS and other alerts.
HF-9	Will pilots' decision-making responses be longer for the synthetic vision system compared to the out-of-the-window system? What are the implications of adding the synthetic vision system to the cockpit? How compatible will synthetic or enhanced vision systems be with existing avionics?
HF-10 (BRC)	What are the pilots' expectations when flying with synthetic or enhanced vision systems? What are the tradeoffs between safety and efficiency when the safety buffer is reduced between aircraft?

<b>Procedures</b>	
P-1 (HF)	Turning over separation responsibility to pilots will require procedures regarding when it can be turned over and how it would revert to the controller. From a controller perspective, workload and frequency congestion may be lower using present procedures and maintaining separation responsibility.
P-2	ALPA has maintained opposition to pilot assumption of separation responsibility other than as used today with visual approaches.
P-3 (HF)	Wake Turbulence Tool -- The benefit is limited because controllers would presumably be responsible for ensuring normal wake turbulence separation was applied until advised by the pilot that the new tool on the SVS is being used. It will require transmissions and time on frequency to pass this information and an instruction to execute a new procedure to maintain wake separation using the SVS. The controller will have to be cognizant of which aircraft are so equipped. Controller workload may not decrease overall even if pilots are responsible for separation.

<b>Procedures</b>	
P-4 (HF)	Mixed Equipage (SVS, non-SVS) -- This will be a fact of life. From a controller perspective it requires a method to advise the controller of equipage, awareness of the equipage by the controller, grouping like-equipped aircraft and segregating non-equipped aircraft. These duties coupled with the procedures and phraseology inherent in any new procedure will likely increase controller workload.
P-5	Departure Procedures -- This discussion does not take into account possible problems with an intermix of aircraft such that some aircraft might be SVS equipped, while others are not equipped. This could also affect separation issues and would be a factor for ATC and the pilot.
P-6 (BRC)	Enabling closely-spaced parallel IMC departure -- Same problem as above. While some benefit might be gained, it is the non-equipped aircraft that will be the limiting factor for traffic enhancement.
P-7 (BRC)	Parallel Departures Same problem as above. Should include reference to a total system using SVS in order to have capacity enhancement or a limited enhancement with a mixed system.
P-8 (HF)	The transfer of responsibility of traffic separation from controller to the cockpit needs to be well thought out. The pilot unions and ATC around the world need to be in the loop when working on these types of changes. All parties need to be involved from the beginning. Certainly the person with the best tools should be performing the task. Time delay in relaying instructions becomes a real factor with closer spacing. Combined pilot/controller simulations seem highly desirable.
P-9	While it is assumed that TCAS, perhaps even other cooperative means, is operative, what about detecting the non-cooperative traffic – like traffic without an operable transponder. Even an assumption that every aircraft must be equipped with an operative transponder – equipment failures occur, pilots sometimes fail to turn them on, and so forth.
P-10	What is the timing constraint associated with synthetic vision? Are the emergency procedures different between the synthetic vision out-of-the-window systems?
P-11 (HF) (BRC)	What is the potential impact for air traffic control requirements? Do we want synthetic vision to be apparent to only pilots, only controllers, or to both pilots and controllers? If pilots only, controllers only, or both, these questions must be addressed: what is the safety buffer between aircraft? What are the procedures during VFR and IMC? What are the VFR and IMC procedures for synthetic vision and non-synthetic vision systems operating in the same airspace, airport, or taxiway? does the safety buffer change compared to the two systems?

<b>Simulation</b>	
S-1	SVS has immense potential as a simulation tool, but is only briefly touched upon. Bring up the subject much sooner in the document too.
S-2 (D)	Additionally, weather is treated almost as an afterthought throughout the document, but it is the impetus for the SVS. I believe weather should be treated with the same enthusiasm as any other physical hazard. DoD is working hard to create realistic weather scenarios. If you're interested review the attached document. Our web site will help also. I believe you may be most interested in the Cloud Scene Simulation Model (CSSM).
S-3	An additional spin-off for SVS would be better visuals for the traditional simulator.

<b>Sensors and Databases</b>	
SD-1	In order for the Runway Incursion Scenario to be effectively avoided, it is important to provide pilots with thrust lever position information from airplanes in the traffic pattern and on the ground maneuvering. This information cues pilots as to when an airplane is about to accelerate onto a runway, accelerate for takeoff, go around, perform an RTO, etc. This kind of information is essential if it is expected that pilots are to close up spacing with airplanes ahead to a minimum.

<b>Sensors and Databases</b>	
SD-2	Serious consideration should be given to the exchange of airplane acceleration data as a means of preventing runway incursions. If an airplane is going to inadvertently pull out onto the runway, creating a collision threat, it must first accelerate, if it has been holding short.
SD-3	SVS paired with ADS-B has great potential for allowing a runway incursion to be predicted. An immediate EICAS warning could be issued to the crew. This is possible since the FMC knows the runway intended to be used for takeoff. The incursion boundary would be in the airport surface database. It would know the positions other aircraft on the airport surface and their current speed/acceleration. It could use algorithms to predict a runway incursion with some finite lead-time.
SD-4	Data that would be of value in predicting runway incursions would be things that indicate expected movement (e. g., park brake on/off, thrust reversers open/closed, and intended runway exit to be used).
SD-5	SVS, when paired with ADS-B, has the excellent potential of preventing a runway incursion accident, such as happened involving two Boeing 747 aircraft at Tenerife. These types of accidents are actually becoming more likely as time goes by. They, by definition involve more than one airplane, making them doubly tragic.
SD-6	It was not clear as to whether the SVS primary inputs would be from on-board sensors or terrain data or both. Past experience indicates that this aspect needs to be considered carefully. Sensor Displays... As examples: A) MMWR and FLIR have been shown to have problems in either achieving the necessary performance technically or within reasonable cost for the markets being addressed here. This creates significant problems particularly on low approaches. B) The source of terrain databases may not support the accuracy necessary to provide SAFE terrain clearances for the operations described. Maybe the last shuttle data is acceptable, but past data is a problem. C) How will structures and man made changes be addressed in the database for SVS around airports. Maybe this will use some radar to find and identify these real time changes.
SD-7	SVS brings to mind some shortfalls in local simulations, some of which can only produce visibility restrictions (faded images) as their only weather impact. If Synthetic Vision ever evolves to include passive sensors that can produce a real image of the real runway/taxiway, then a simulation capability must accompany the capability in order to assess and understand when the sensors will and will not work in the real atmosphere. This simulation capability must include the atmospheric attenuators of the sensor signal, such as drop size distribution, and must be based on measured drop size distributions for fogs of various types, for rain and for snow. It must evolve with time in a realistic way (such as a marine fog spreading across the airport; and fog break-up/dissipation in late morning). It must include real runway/edge contrasts for intended use airports as well time of day effects on contrasts for visible, IR and millimeter wave (Radar) sensor systems.
SD-8 (D)	Departure Display Features. A discussion on how NASA envisions data integrity will exist for terrain and obstacle changes, might improve pilot enthusiasm for the project.
SD-9	Wholly agree with the statement that substantial differences in visibility can exist, simultaneously, at the airport. Not only is visibility spatially non-homogenous, it is also variant over short time intervals. By the way, for imaging sensors that work outside the visual spectrum, there is currently no means to equate visibility to sensor performance. This places a burden on the use of such SVS equipment and a further opportunity for the program to foster the development of such capabilities. [How will sensor performance be compared to VMC viewing?]
SD-10	It will be important to establish, objectively, the real performance of sensors that would be used for hazard detection. Please do not stop at investigation system capabilities on a presumption that sensors would perform adequately. In fact, one of the most lasting legacies of this project could be the collection, analysis and modeling of sensor performance in the expected environmental conditions (atmosphere, scene, targets, airplane).