Concept of Operations for Commercial and Business Aircraft Synthetic Vision Systems

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Version 1.0 (Draft)

June 2000

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Abstract

A concept of operations (CONOPS) for the Commercial and Business-jet (CaB) aircraft synthetic vision system (SVS) is described. The CaB SVS provides increased safety and operational benefits in normal and low visibility conditions. Providing operational benefits will promote SVS fleet implementation, improve aviation safety, and assist in meeting the President's national aviation safety goal. SVS will enable enhanced safe and consistent gate-to-gate aircraft operations in normal and low visibility conditions. The goal for designing an SVS is to support operational minima as low as Category IIIb. For departure and ground operations, the SVS goal is to enable head-down operations with an RVR of 300 feet. The system is an integrated display concept that incorporates features of a primary flight display and navigation display superimposed on a representation of terrain and may also include displays of information from sensors. The operational concept is described in terms of the operational functions of the system, the elements of the display, and procedures specified to support some specific applications in the ground operations, departure, en route and approach phases of flight. The applications selected for particular emphasis in this document include low visibility arrivals and departures including parallel runway operations, and low visibility airport surface operations. These particular applications were selected because SVS support to these operations offers cost-effective benefits.

1 Introduction

This document describes the concept of operations (CONOPS) for commercial and business-jet aircraft (CaB) synthetic vision systems (SVS). It is intended to describe "how to use" SVS technologies and provide an operational focus for CaB SVS research, development, and implementation.

In August 1996, following several high-visibility commercial transport accidents, a White House Commission on Aviation Safety and Security was established to study matters involving aviation safety and security. In February 1997, in response to the Commission's recommendations, President Clinton set a national goal to reduce the aviation fatal accident rate by 80% within ten years. NASA formed the focused Aviation Safety Program (AvSP) to meet this goal. NASA's AvSP Synthetic Vision Systems (SVS) Project intends to develop and support the implementation of synthetic vision systems for commercial transport and business jets (CaB), general aviation (GA), and rotorcraft applications to improve safety in low visibility operations.

The current climate of the commercial air transportation industry has also driven a demand for seeking improved benefits through more flexible operations in low visibility conditions. Air traffic controllers, airlines and pilots are continually voicing their need for more operational flexibility from increased situation awareness (SA) 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 required in low visibility conditions.

With the expected growth of the worldwide aircraft fleet, aviation incidents are projected to increase in number unless the aviation industry is made safer and the incident rate is decreased. One of the largest causal factors of aviation incidents is poor situation awareness in low visibility conditions. Low visibility forces pilots to become the integrators of disparate forms of data and information as well as fly their aircraft. Low-visibility induced incidents include controlled flight into terrain (CFIT), runway incursions (RIs), and those due to flight path navigation errors. Poor visibility also hampers overall operations effectiveness and creates costly air transportation system delays. The economically competitive airline industry requires safety enhancements to be imbedded into increased operational capability in order to provide an economic incentive or "compelling business case" to implement new technology. ***The CaB SVS must provide increased safety and operational benefits in normal and low visibility conditions to promote SVS fleet implementation, thereby improving aviation safety, and meeting the President's national aviation safety goal[1].***

[1] Defined in 1997 to reduce aviation accidents by 80% within ten years.

There are many contributors and stakeholders to the development of a CaB SVS CONOPS including: NASA, DoD, FAA, NIMA, NGS, CaB pilots, airlines, aviation manufacturers, airports, and academic institutions. The unique perspectives of each group or organization are required for the development of a successful SVS CONOPS.

1.1 Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast
AH	Alert Height
AILS	Airborne Information for Lateral Spacing
ALPA	Airline Pilots Association
AMASS	Airport Movement Area Safety System
ASDE-3	Airport Surface Detection Equipment – 3 (ground surveillance radar)
ASIST	Aviation Safety Investment Strategy Team
ATA	Aviation Transport Association
ATC	Air Traffic Control
AVOSS	Aircraft Vortex Spacing System
AvSP	Aviation Safety Program
AWIN	Aviation Weather Information
BLH	Analysis technology: Baseline + HUD
CaB	Commercial and Business Aircraft
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight Into Terrain
CNS/ATM	Communication, Navigation, and Surveillance/ Air Traffic Management
CPDLC	Controller-Pilot DataLink Communications
DFW	Dallas-Fort Worth International Airport
DGPS	Differential Global Positioning System
DH	Decision Height
DROM	Dynamic Runway Occupancy Measurement
DTW	Detroit Metropolitan Wayne County Airport
EFIS	Electronic Flight Instrument System
EGPWS	Enhanced Ground Proximity Warning System
EVS	Enhanced Vision System
EWR	Newark International Airport
FAA	Federal Aviation Administration
FAR	Federal Airworthiness Regulation
FLIP	Flight Information Publication
FLIR	Forward Looking Infrared
FMS	Flight management System
GMTI	Ground Moving Target Indicator
GPS	Global Positioning System
HDD	Head-Down Display

HSCT	High Speed Civil Transport
HUD	Head-Up Display
HUD	Head-up Display
IMC	Instrument Meteorological Conditions
JFK	John F. Kennedy International Airport
LAAS	Local Area Augmentation System (high accuracy satellite guidance system)
LAHSO	Land and Hold Short Operations
LaRC	NASA Langley Research Center
LCD	Liquid Crystal Display
LNAV	Lateral Navigation
LVLASO	Low Visibility Landing and Surface Operations
MIT	Miles-in-trail
MMWR	MilliMeter Wave Radar
MSP	Minneapolis-St Paul International Airport
NAS	National Airspace System
ND	Navigational 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
RI	Runway Incursion
RIPS	Runway Incursion Prevention System
RIRP	Runway Incursion Reduction Program (FAA)
ROT	Runway Occupancy Time
ROTO	Roll-Out, Turn-Off
RTCA	(Formerly) Radio Technical Commission for Aeronautics
RTO	Rejected Takeoff
RVR	Runway Visual Range
SA	Situation Awareness
SAR	Synthetic Aperture Radar
SEA	Seattle-Tacoma International Airport
SMGCS	Surface Movement Guidance and Control System (pronounced "SMIGS")
SRTM	Shuttle Radar Topography Mission
SUA	Special Use Airspace

SV1 to 3	Analysis technologies: Synthetic Vision
SVS	Synthetic Vision System
TAWS	Terrain Awareness and Warning System
TCAS	Traffic alert and Collision Avoidance System
TCAS	Traffic Alert and Collision Avoidance System
TIS-B	Traffic Information System-Broadcast
T-NASA	Taxiway Navigation and Situational Awareness
TSRV	Transport Systems Research Vehicle
UAV	Unmanned Aerial Vehicle
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 led up to current SVS capability. 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 in low visibility is steadily increasing with several commercial products available[2]. Several key initiatives in recent years include:

- NASA/FAA Millimeter Wave Radar (MMWR) and Forward-Looking Infrared (FLIR) flight research
- Head-Up Display (HUD) development
- Helmet-Mounted Sight development
- Tunnel/Highway-in-the-sky development
- Military Development of Terrain Following Radar, Synthetic Aperture Radar (SAR), Ground Moving Target Indicator (GMTI), and FLIR technologies
- Mapping, Charting & Geodesy (MC&G) Improvements – especially 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 on and off-board sensors
- Computing Technology (especially processing speed and memory) growth

[2] Sierra Flight Systems EFIS 2000 with a terrain display; several HUDs are also available

Figure 1.1 NASA Langley SVS Depiction of Approach to Asheville, NC … Developed for the HSCT

Figure 1.1 illustrates the present maturity of SVS technology. Shown is a state-of-the-art display with symbology providing 4D precision navigation information integrated with a photo-realistic terrain and object database. Using this SVS display, test pilots flew approaches to touchdown in November 1999.

1.3 CaB SVS Development Process

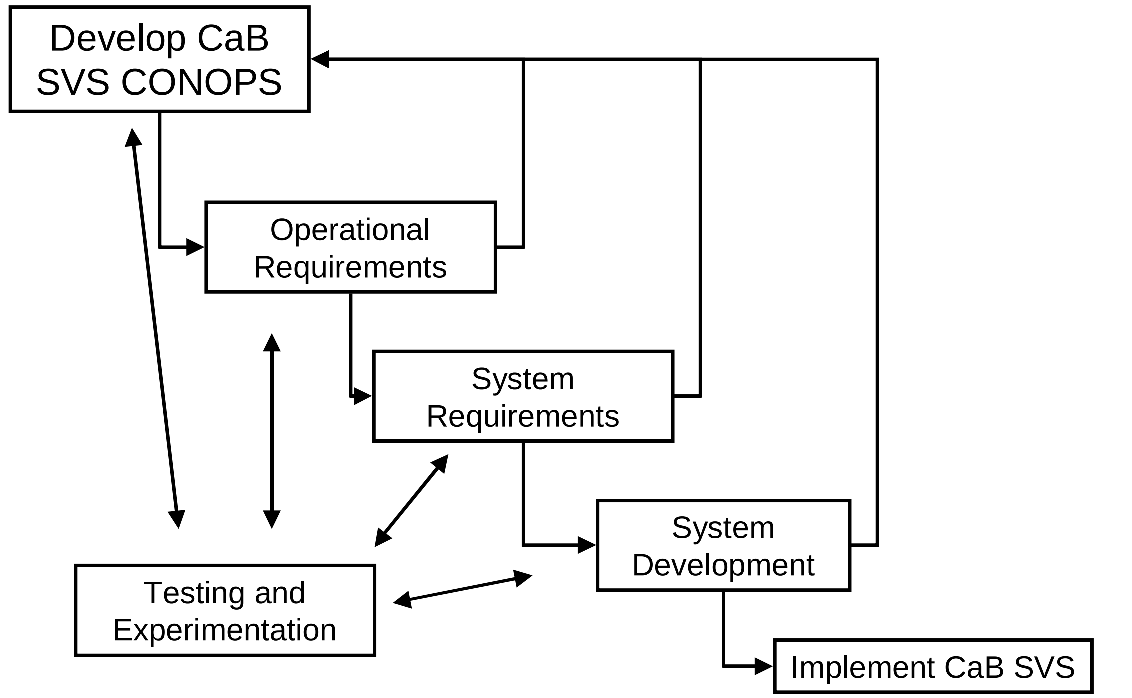

Figure 1.2 CaB SVS Development Process

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, operational requirements will be derived to give an operational focus to system requirements for system development. In NASA's AvSP, CaB SVS development will be done at NASA Langley Research Center and in partnership with private industry through cooperative agreements. Once systems are developed, they can then be tested through experimentation, refined and then implemented within CaB aircraft. 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.

1.4 CaB SVS Project Objectives

The general objective of the CaB SVS Project is to develop cockpit display systems with intuitive visual cues that replicate the safety and operational benefits of flight operations in clear-day Visual Meteorological Conditions.

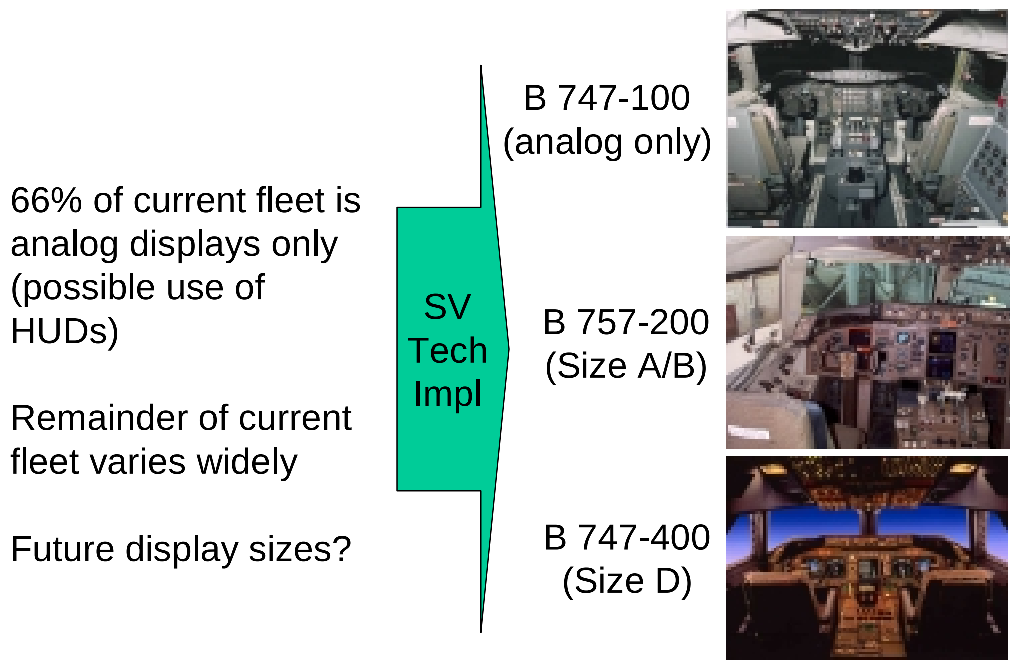

Figure 1.3 Challenges to SVS implementation -- *Variations of cockpit displays*

The following specific objectives advance the development of synthetic vision display and infrastructure technologies; provide the supporting empirical evidence of the efficacy of this approach for eliminating the targeted accident categories, and advance the implementation readiness levels for this technology:

1. Develop and demonstrate affordable, certifiable, display configurations (including retrofit – Figure 1.3) to provide intuitive out-the-window terrain and obstacle information suitable for commercial transports and business jets.

2. Develop and demonstrate synthetic vision display concepts, which provide enhanced terrain awareness for proactive avoidance of CFIT precursors.

3. Develop and demonstrate enabling technology to provide intuitive guidance cues with necessary terrain and obstruction information for

precision approach and landing using terrain, obstacle, and airport databases and GPS derived navigation.

4. 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.

5. Validate through high fidelity simulation studies that proposed display concepts reduce CFIT, RI, and other visibility-induced fatal accident rates.

6. Develop and demonstrate the operational benefits (compelling business case) of synthetic vision systems that will motivate the commercial aviation industry to invest in SVS development, acquisition, and implementation while improving aviation safety.

7. 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 the evolving National Airspace System (NAS).

1.5 CaB SVS Mission

SVS will enable enhanced safe and consistent gate-to-gate aircraft operations in normal and low visibility conditions. The CaB aviation industry believes it is safe and is unlikely to purchase SVS solely for safety's sake, but will purchase SVS for a better capability to accomplish the mission of moving people from Airport A to Airport B. Therefore, the CaB SVS must be focused on operational benefits through mission accomplishment for aviation industry acceptance.

SVS will support safe aircraft operations gate-to-gate (taxi, departure, en route, arrival/missed approach, landing, taxi, shutdown). It may be feasible to apply SVS technology in zero visibility. However, Category IIIc or "zero/zero[3]" operations are not an approved operation at this time, and the weather minimums that would require Category IIIc use are rare. Furthermore, conducting "zero/zero" operations requires enhanced equipage of emergency response vehicles. Consequently, the focus of this CONOPS will be on allowing operations in normal and "low visibility" or Category IIIb or better visibility conditions. SVS will allow greater operations flexibility such as permitting aircraft to taxi, depart, and arrive in Category IIIb visibility while using Category I equipped airports and runways. Therefore, the potential operational benefits are also a major area of CONOPS consideration. **The goal for designing an SVS is to support operational minimums as low as Category IIIb. For departure and ground operations, the SVS goal is to enable head-down operations with an RVR of 300 feet.** (See Appendix B for visibility category definitions)

[3] Ceiling and runway visibility range.

2 The SVS Operational Concept

The SVS concept will be described in terms of its four operational functions, its four system elements, and the procedures that are employed in using SVS technologies in key applications. The discussion of the functions will identify the operational capability SVS must support. The system elements discussed are the characteristics of SVS that can be applied to meet the operational functions. The procedures section will describe how pilots will use an SVS in each flight phase.

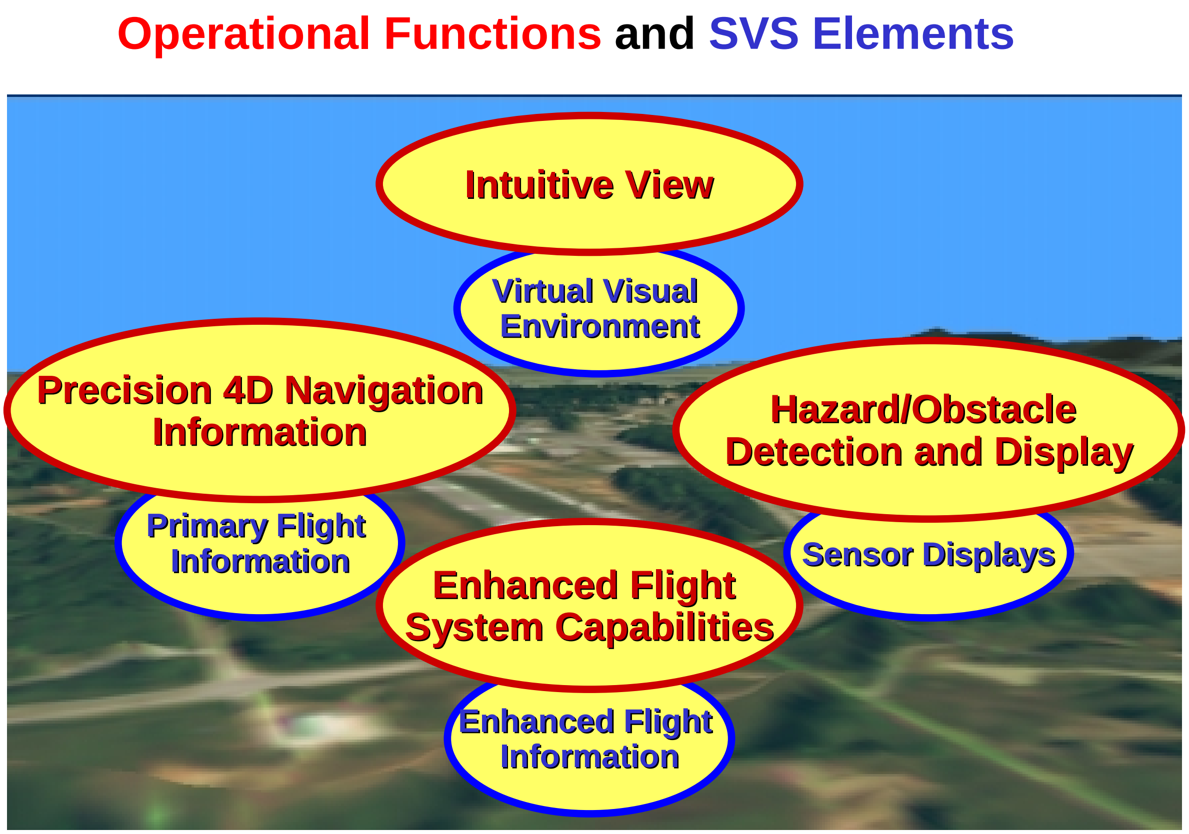

Figure 3.1 Operational Functions and SVS Elements

2.1 Operational Functions of the SVS

The operational functions of the SVS are to:

- *Provide An Intuitive view of the terrain in low visibility conditions* – The SVS will provide a view of the environment in which the aircraft is operating – intuitive to the pilots, similar to what pilots see "out of the window." SVS will therefore provide enhanced situation awareness in low visibility operations that is expected to enhance operations, reduce pilot workload and increase safety. The SVS will enable pilots to fly in the proximity of challenging terrain in a manner similar to adhering to visual flight rules (VFR) in visual meteorological conditions (VMC).

- *Provide Hazard/Obstacle Detection and Display* – Hazard and obstacle avoidance are prerequisites for safe operations in all flight phases and must include monitoring database integrity. Items of concern include: ground and air traffic, construction areas, newly built structures, wildlife, wind-shear, wake vortices, turbulence, icing zones, etc.
- *Provide Precision 4D Navigation Information* – SVS provides an intuitive primary flight information interface for precision flight-path navigation enabled by GPS. Using the SVS virtual visual display, pilots can view own-ship location accurately and rapidly correlate navigation to terrain features. This element enables the pilot to access and monitor the path following accuracy of the SVS system and is crucial for lowering required navigation performance (RNP) minimums.
- *Support Enhanced Flight System Capabilities* – Beyond primary flight information, pilots require prioritized pro-active decision-making information to support functions like: self-separation, curved IMC approaches, noise abatement procedures, low visibility taxi operations and departures, mission rehearsal.

2.2 SVS Elements

The elements of the SVS include: a Virtual Visual Environment; Sensor Displays; Primary Flight Information, and Enhanced Flight Information. It is envisioned that SVS elements would be integrated in a head-down or head-up display system. The virtual visual environment may have a depiction of a terrain database background with multi-system information superimposed on it, or ultimately integrated into it in a seamless system. Since cluttered displays are not desirable, pilots should be able to choose a desired scale or select specific elements of the overall SVS, so prioritized information is used. Information displayed can be pilot selectable or depicted as a function of phase of flight. SVS can be described as an integration of information and interfaces conventionally available in flight decks, particularly glass flight decks. An SVS will extend conventional display concepts to be more intuitive and will include a graphical illustration of the flight environment with integrated information from non-flight-critical and flight-critical systems.

- *Virtual Visual Environment* – The central idea of this SVS element is to provide pilots an intuitive display of information that mimics what could be seen out of the window in good visibility. This element would also incorporate enhancements to the view to highlight important features that are relevant to safe and efficient operation of the flight even in good visibility. The virtual visual environment is largely derived from showing the terrain database integrated with other information sources. The terrain and obstacles might be implemented in a detailed photo-realistic format; as less detailed terrain texture, as wire-frame drawings that illustrate important features of the terrain, or through some other graphics format. The illustrated portion of this element will be rendered from databases that include three-dimensional terrain, cultural data, and significant obstacle structures (including buildings and towers). The virtual visual environment view can include the following:

1. An accurate representation of the location of own aircraft with respect to other features shown in the display.
2. Traffic aircraft and surface vehicles in the proximity of own aircraft.
3. Terrain features in the proximity of own aircraft.
4. Obstacles such as buildings, towers, and other structures that are in the proximity of own aircraft.
5. Target structures that may be associated with the current operations, such as a gate or a deicing facility.
6. A view of the runway edges and centerline in departure operations.
7. Wake turbulence protection must be incorporated either using procedures to safe guard against encounters or detection and avoidance systems that may be airborne or ground based. A highly promising new technology in this area is NASA's Aircraft Vortex Spacing System (AVOSS)[4].

- *Sensor Displays* – Many implementation variations are possible with on-board sensor images and should match the particular application desired. Such variations include the display of un-processed, processed, integrated and fused data. The purpose of displaying on-board sensor imagery is for object/hazard detection and database integrity monitoring. Various sensor images can be overlaid, processed, integrated or fused. Salient features/hazards can then be highlighted or depicted as symbols or icons. Since the cost of sensors, their processing, and display integration is significant, an operational cost-benefit analysis can be performed to determine the best application area(s) for them. Broader versions of SVS would include imaging sensors such as video cameras, conventional radar, or FLIR.
- *Primary Flight Information* – This element comprises the information conventionally presented in the primary flight and navigation displays of a flight deck and is the interface for precision navigation information. It presents information necessary to support the pilot in flying the aircraft. It includes information such as the aircraft's attitude, airspeed, ground speed, altitude, vertical speed, velocity vector, and location with respect to navigation fixes.
- *Enhanced Flight Information* – Operational functions can be enabled through an SVS depiction of enhanced flight information such as a tunnel/pathway, wireframes, navigation cues, CDTI, hazard depictions and alerting, taxi maps, flight or taxi-path aids. Self-spacing algorithms can be integrated into SVS displays and could facilitate improved operational benefits. Using a pathway-in-the-sky, IMC curved approaches and departures can be flown while avoiding hazards and noise sensitive areas. Also, if alerts are used in the display to warn of traffic or terrain, any

[4] AVOSS is a developing ground-based technology that provides controllers accurate wake vortex information so they can space aircraft accordingly. This system is designed to allow closer in-trail spacing and the corresponding operational benefits than a rule-based method.

associated symbols would be a part of this enhanced flight information. Abnormal flight operations procedures to include missed approach, emergency escape maneuvers and real-time flight planning and mission rehearsal as a part of emergency operations could also be assisted by these SVS enhancements.

2.3 Procedures for Using the SVS – By Flight Phase

An SVS will support operations during all phases of flight. This section will describe applications that are of particular interest and discuss their operational procedures. Appendix A contains summarized descriptions of many potential SVS applications that were recorded at the February 2000, CaB SVS CONOPS Workshop.

2.3.1 Ground Operations Between Gate and Runway

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. The SVS will enable the safety and efficiency associated with clear daylight operation to be realized at night and in low-visibility surface operations. An SVS can provide the pilot with information and cues to navigate assigned taxiways to prevent airport gridlock, eliminate incorrect path choices, and avoid all obstacles while taxiing at normal speeds in all visibility conditions. Optimal surface operations can be achieved by providing virtual cues in an SVS display that complement or replace the visual cues provided by standard low-visibility airport features such as signage, lighting, and markings. Appropriate, familiar, and intuitive displays of path guidance and obstacles, whether they are stationary or moving, man-made or natural, must be presented in such a way as to prevent runway incursions and any other deviation from safe operations. Such a system will not only provide operations equivalent to those exhibited in clear daylight visibility, but will inspire crew confidence, alleviate taxi clearance misunderstandings, and greatly reduce confusion in the cockpit especially at airports with complex layouts and also in night operations.

2.3.1.1 Relevant Technologies and Research

Several established and emerging programs address low-visibility surface operations. The Low Visibility Landing and Surface Operations (LVLASO) project at the NASA Langley Research Center was designed to develop and demonstrate technologies that will safely enable clear weather capacities on the surface in Instrument Meteorological Conditions (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 situation awareness on the flight deck such that taxi operations can be performed safely and efficiently regardless of visibility, time of day, airport complexity, or airport unfamiliarity. A Dynamic Runway Occupancy Measurement (DROM) system was designed to capture runway occupancy times in real-time. A database of these times is maintained that can be used 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 position symbology and provides situation awareness and timely warning of potential conflicts. Supporting technology includes datalink, position determination system, surveillance system and controller interface.

In addition, system integration activities are being performed to demonstrate operational feasibility, generate/validate requirements, and to assess candidate supporting technologies (e.g. DGPS, CPDLC, ADS-B, TIS-B, and ATC displays). A holistic systems approach has been taken that attempts to be compliant with the Free Flight, CNS/ATM, and A-SMGCS concepts. The FAA's Surface Movement Guidance and Control System, SMGCS, (pronounced 'SMIGS') requires a low-visibility taxi plan for any airport which has takeoff or landing operations with less than 1,200 feet RVR visibility conditions.

2.3.1.2 Airport Ground Operations in Reduced Visibility

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. It is a relatively small step in technology to enable both takeoffs and landings in zero visibility conditions, however the ability to takeoff and land in zero visibility is meaningless if the aircraft cannot taxi and the many support functions on the ground cannot operate normally. Therefore, a practical and achievable minimum visibility should be selected to serve as the standard for future research. This standard should be applied to all areas of airport operations. The benefit of SVS is not in simply enabling takeoffs and landings in zero visibility, but in other related ground operations.

Goals of SVS for ground operations are:

1) Providing a means of operating in the ground environment in conditions of reduced visibility (300 feet RVR) with levels of safety and efficiency equivalent to visual meteorological conditions (VMC).
2) Reducing or eliminating runway incursions at night and in conditions of reduced visibility as well as in normal conditions.
3) Reducing takeoff minimums (currently 600 feet RVR) to that of the lowest landing minimums.

Item 1) is, depending on the visibility goal established, the most complex to solve since accommodating ground vehicular traffic would be a factor. It is likely that the goal of operating with VMC-levels of safety and efficiency in true zero visibility conditions is neither realistic nor cost-effective.

To fully appreciate the complexity of this issue, the following scenario is offered:

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 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.

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[5] 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 TV 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 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 on an aircraft will not be beneficial.

Fog is rarely a homogenous phenomenon. Runway Visual Range (RVR) is measured adjacent to a given runway at three points: touchdown, mid-field and roll out. It is important to understand that substantial differences in visibility can exist on the airport. Local conditions such as heated buildings, hot aircraft engines or areas of moist, cool grass can have a profound influence on visibility. Table 3.1 reflects the variations that can be expected when operating in the vicinity of a runway reporting various Runway Visual Ranges.

[5] Ramp – Area of an airport that is controlled by an airline. Includes gate operations for several gates.

Table 3.1 Operational Implications of Runway Visibility Ranges	
RVR (feet)	DESCRIPTION
5000	Airport and aircraft operations are normal both daylight and night.
2400	Taxi speed may be reduced somewhat below the normal straight-ahead taxi speed of 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 0:30 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).

In view of the above discussion, operation in true zero-visibility conditions severely constrains even local gate operations and a practical solution is probably not attainable. Visibility in the range of 150 to 600 RVR could benefit from an integrated SVS system, one that includes essential ground vehicles in the plan. Any system that has as a goal of VMC-equivalent operation in specified visibility conditions must provide a solution for ground vehicles operating outside of the immediate gate area.

Such operations may also depend on sensor based obstacle detection or detection of other vehicles or traffic. Some applications will also require data exchange between aircraft such as with TCAS and ADS-B.

2.3.1.3 Display Features

Figure 3.2 contains examples of ground operations displays used in low-visibility research at NASA (see Ref 4).

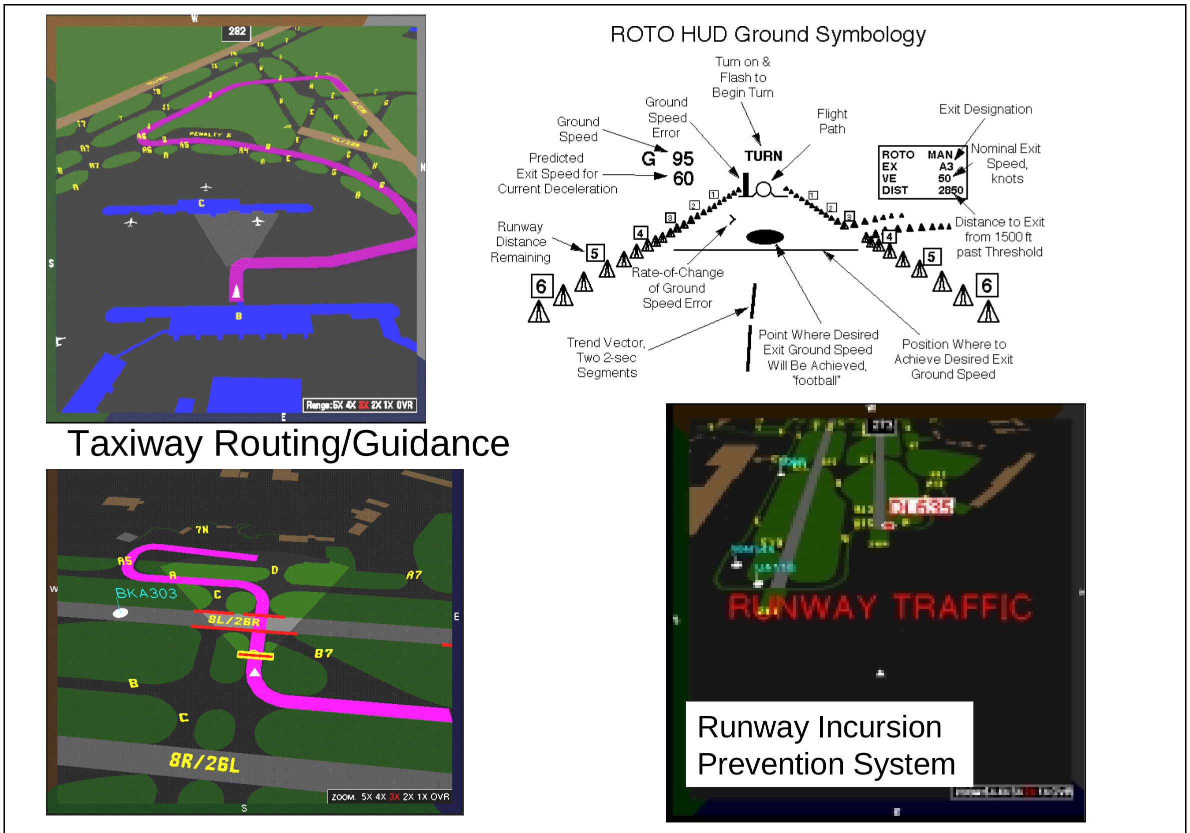

Figure 3. 2 Notional Ground Operations Displays and Features (LVLASO, T-NASA, ROTO, RIPS)

2.3.2 Departure

SVS development for the departure phase of flight will focus on enabling departures in low visibility when the runway visual range is 300 feet or more[6].

The departure phase of flight begins 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.

Before entering the active runway, the flight crew will, to the extent that they are able given existing visibility and topography, visually check the approach to the runway and the runway itself for traffic and obstacles. An SVS will enhance safety by extending the pilot's visual recognition range and providing warning independent of visual obscurations. While taxiing to the runway or after holding

[6] 300 feet RVR has been determined by operational benefit modeling analysis to be a "breakthrough point" where operational/economic payoff increases sharply for an SVS capability.

at the runway end, the flight crew acknowledges ATC clearance, “cleared for takeoff” and begins the takeoff. SVS must depict runway edges and centerline to support the takeoff.

During the takeoff, airplane engine instruments are monitored for proper indication. Flight instruments have independent sources for power and data for the left and right. Indications are compared during the takeoff roll, and most CaB operators incorporate an "eighty knot[7]" check. V_1, V_R, and V_2 are announced by the PNF, confirming what the PF sees on his/her airspeed indicator. The decision to reject the takeoff becomes more dangerous as the aircraft accelerates so an SVS should provide early object and traffic detection, preferably before the takeoff roll has begun.

When 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[8]. This requires an intuitive view of relevant traffic and allowable trajectory that the aircraft can fly. The display can include the boundaries of allowable deviation, and a “safe corridor” or tunnel to avoid terrain and traffic.

If there is departure traffic from a parallel runway or from an aircraft executing a missed approach, there must be a clear and safe escape procedure using the SVS display should one aircraft deviate from its nominal path and threaten the other. This capability, along with a visual depiction of the traffic, is required for allowing pilots to accept responsibility for separation.

The SVS provides a conformal view of an aircraft’s environment. In particular, the runway outline and centerline, surrounding terrain, and known obstacles are depicted on the PFD. Additionally, ground and airborne traffic and runway obstructions are visible on the forward-looking display. The capability to maintain directional control and reject takeoffs exists using the head-down PFD regardless of visibility.

2.3.2.1 Departure Procedures

A takeoff with an SVS would require that air traffic control (ATC) be aware that the aircraft was SVS equipped only if separation[9] is an issue. The pilot flying (PF) would view the PFD depiction of the runway, traffic and obstacles while the pilot not flying (PNF) would, in addition to normal PNF tasks, look out the windshield for additional verification if the visibility allows, or at the PFD if visibility is low.

[7] Dependent on the aircraft type.
[8] Especially to maintain situation awareness of traffic on an adjacent runway if it is closer than 2500 feet laterally.
[9] It is the pilot’s responsibility to comply with visibility minimums, not that of ATC.

Once airborne, visual separation from parallel traffic could be maintained using the same forward looking display[10]. Path and terrain depiction would give the crew the added situation awareness important in certain terrain impacted departure operations.

2.3.2.1.1 Single Runway Departures

The following are VMC restrictions and procedures in single departure environments[11]:

1. There are standard departure minimums 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 other than standard, they supersede the standard requirement and are generally more stringent and will typically include a ceiling. They frequently implement requirements to clear terrain features or other obstacles.

2. ATC will clear the flight for takeoff, insuring that no other traffic is on the runway or in the departure path.

3. The tower controller is normally expected to see the runway, or at least insure that the runway is clear of traffic before a take-off clearance is given.

2.3.2.1.2 Enabling closely-spaced[12] parallel IMC departures

There are conditions in departure operations that enable aircraft to depart airports in VMC when the runway separation is closer than 2500 feet. When these conditions can not be met because of weather minimums, restrictions are placed on the departure operations that lower the number of departures from the airport. In order to specify how an SVS will support departure operations in IMC, we must clearly understand how these departures are conducted in VMC operations. The roles and responsibilities of the flight deck crew and of ATC must be clearly specified. Then an SVS-based procedure can be specified that includes each function that is carried out in VMC operations.

The first thing to consider is that 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.

[10] Determining the required display size and field of view is the subject of a current NASA LaRC simulation experiment study.

[11] Where there is no conflict with parallel departures closer than 4300 feet laterally or departures from a crossing runway.

[12] Less than 2500 feet

2. The pilot must be able to guide the aircraft accurately along the runway during the run up to take-off speed.

3. The pilots must have access to the information normally provided by flight instruments to support take-off operations. This includes the PFD, ND and airspeed displays with their normal functionality for takeoff, presenting V_1, V_R, and V_2.

4. 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 the parallel traffic and will accept the responsibility (visual separation). When the tower controller maintains the responsibility, normally 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.

5. Within some accuracy limits 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.

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

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

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 them onto appropriate diverging courses immediately after takeoff.

3. The tower controller has the option to maintain visual separation responsibility and not put them on diverging courses. However, some form of standard separation must be applied before the aircraft departs tower airspace or the tower controller loses visibility.

2.3.2.1.4 Parallel Departures in VMC on runways spaced closer than 2500 feet

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.)

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

1. ATC does not have to apply wake turbulence separation standards 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.

2.3.2.1.6 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.

2.3.2.1.7 The use of an SVS in IMC Departures

The question that must be addressed now is how, in departure operations, to provide all of the capabilities to that environment that will allow parallel runways to continue to operate as independent or similarly capable parallel runways.

The visual presentation must have characteristics that enable the pilot to actually make a takeoff with the view provided. The SVS system can enable departures in reduced visibility by providing the flight deck with the capability to:

1. View the runway edges and centerline based on accurate and reliable sensing of its own position and the runway edges and centerline. The pilots must be able to guide the aircraft accurately along the runway centerline while accelerating to takeoff speed. For example, pilots normally make takeoffs head-up. Parallel traffic should also be depicted.

2. Display sensor based information that will detect and warn of obstacles on the runway that may pose a threat to the safety of a departure operation.
The sensors will include onboard instrumentation such as FLIR or other radar, and data-linked information from airport surface surveillance equipment.

3. Display pathway-in-the-sky-like guidance to enable the pilot to establish on a safe departure path. A more conventional guidance display format may also be evaluated for use. That path will comply with standard separation between it and any flight that may be departing from an adjacent runway. This capability would apply to operations on a parallel departure runway that may be more closely spaced than 2500 feet. The system will provide adequate alerts to the pilot when there is inadequate adherence to the prescribed path.

Separation requirements for departure operations in closely spaced parallel environments might require technology similar to Airborne Information for Lateral Spacing (AILS, See refs 1& 2) and paired-staggered operations to enhance safety (see ref 3). These features will protect the flight from traffic hazard by providing alerting and other safety features. It is assumed that TCAS will be functional during departure operations.

2.3.2.2 Operational Considerations

A consequence of relying on the SVS displays for centerline guidance and visibility of traffic and obstacles is the reduction of visibility minima restrictions. It will enable the pilot to depart any runway, including those runways not equipped with centerline lights, with any visibility.

There are also operational implications for airports that have multiple runway departures. When departing aircraft are equipped with an SVS, visual departures on parallel runways are possible in any visibility. When adjacent aircraft are both SVS equipped, air traffic controllers can apply visual separation standards and the aircraft can maintain visual contact until they diverge.

Visual separation procedures may also apply when a departing aircraft and an aircraft executing a missed approach are both SVS equipped.

2.3.2.3 Using SVS to Prevent CFIT in Departure Operations

The SVS provides an intuitive, clear day view of the terrain along the path of the aircraft. The SVS display should include a prediction of the path of the aircraft relative to terrain or obstacles using current state information. It will present guidance information, for example, in the format of a tunnel in the sky, showing an optimal or planned path. SVS will show any terrain and obstacle threats and also display the performance capabilities of the aircraft to aid the pilot in avoiding CFIT.

2.3.2.4 Using SVS to Prevent RIs in Departure Operations

AN SVS can 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.

2.3.2.5 Departure Display features

1. The runway edges and centerline
2. Weather hazards such as windshear, thunderstorms, turbulence, in the departure path
3. Wake vortex hazards trailing from other aircraft
4. Obstacles on the runway: construction, other aircraft, wildlife, ground support vehicles and personnel
5. Display of terrain features such as mountains and hills that are a factor in the progress of the departure.

6. A predictor of the flight path, showing the proximity to terrain features and other obstacles/traffic.
7. A guidance display will present a clear path for the crew.
8. An alerting capability that warns the pilot of prominent terrain. It may be similar to current enhanced ground proximity warning capabilities but should include more proactive or strategic protection. If alerting features are used, recovery procedures for dealing with alerts must be incorporated.
9. A graphical depiction of terrain, airports, and significant infrastructure, driven from a terrain database. This imagery would be shown in a forward-view head-down display, most likely the PFD. Current PFD symbology, including path guidance, would be superimposed on the database images. Additionally, traffic information received from ADS-B and perhaps weather information would be depicted on this display.
10. A Cockpit Display of Traffic Information (CDTI). This would be a plan-view head down display of the flight path and relative location of traffic. Traffic position information is obtained from ADS-B data. Current Navigation Display (ND) symbology is included in this display.
11. Forward looking sensors, using Forward Looking Infrared (FLIR), enhanced weather radar, or millimeter wave radar (MMWR) technology. The data from these sensors would be the basis of the depiction of obstacle information not contained in the geo-database on the forward-looking PFD.
12. Global Positioning System (GPS) navigation capability. This may be augmented by a differential GPS (DGPS) to achieve the required accuracy.

2.3.3 En Route Operations

AN SVS can support aircrew in their monitoring of flight performance and avoidance of hazards in the en route phase, as well as support their transition into the descent/approach phase.

2.3.3.1 Alerts and Warnings

SVS would include alerts that proactively warn the pilot of a projected flight path that comes close to prominent terrain or obstacles. As a backup to a terrain and obstacle database system, the system should 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 could be provided through SVS integration with an Enhanced Ground Proximity Warning System (EGPWS).

2.3.3.2 System Integrity and Escape Maneuvers

There may be restrictions on the manner in which an SVS system may be used to emulate capabilities of visual flight. There must be a backup capability to support safe operation should an SVS system failure occur since the pilot may not be able to look out of the window and select a path to safety. For example, if flying low near terrain, the system should not allow an aircraft to be put in a situation such that a maximum climb rate straight ahead will not take the flight to safety. Some other escape maneuver may be more appropriate in particular flight environments.

2.3.3.3 En route Display Features

1. Tunnel or pathway in the sky
2. Boundaries of terminal defined airspace, and Special Use Airspace.
3. A view of relevant traffic
4. Weather hazards that may be a factor
5. Prominent terrain that must be cleared (especially for low-level en route)
6. The presentation of primary flight information is assumed

2.3.4 Approach (Arrival) Operations

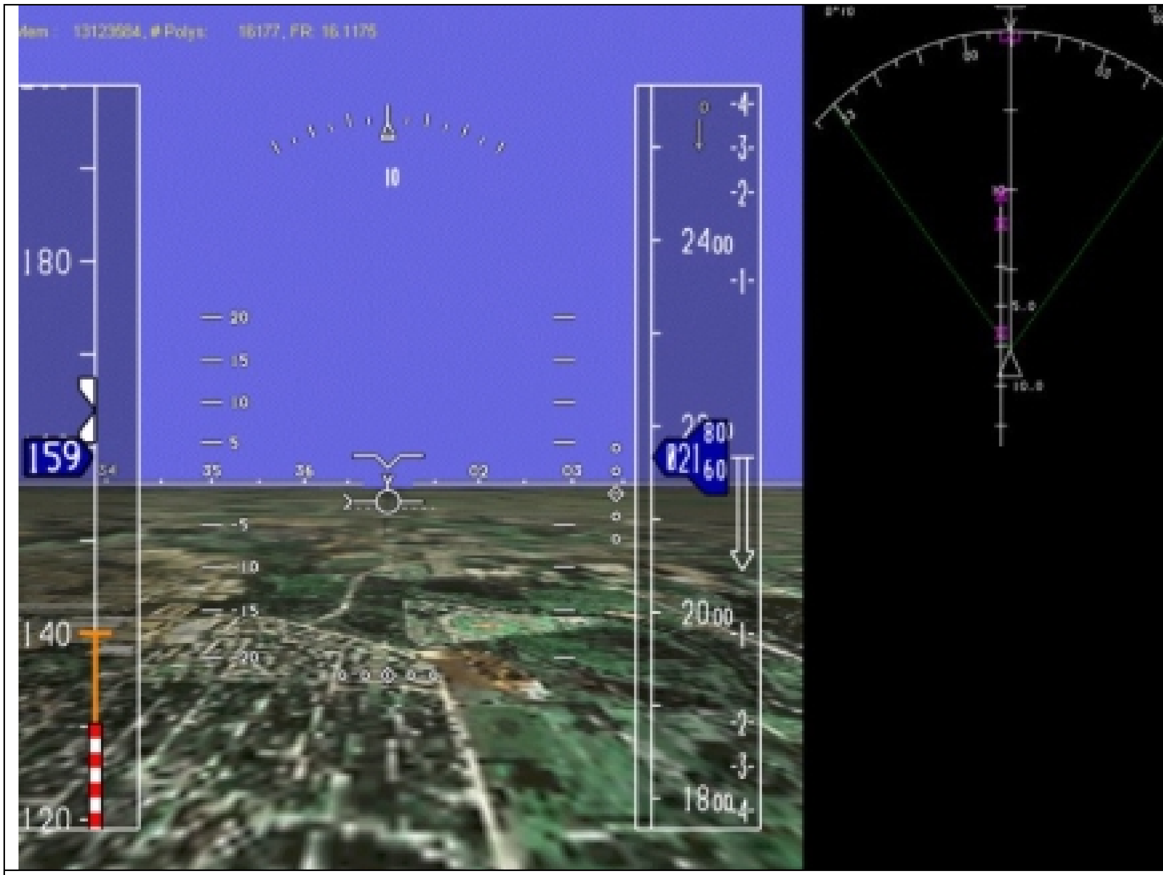

Figure 3.3 Notional SVS Display of DFW Approach

Approach operations have longitudinal and lateral spacing requirements, speed and descent profiles, and weather minimums that impose restrictions on the arrival to an airport. In-trail and lateral spacing responsibility can be transferred from ATC to aircraft operating in VMC. Pilots may visually separate their aircraft from traffic they are following and from parallel runway traffic. In IMC, separation is currently controlled by ATC, and approaches are not conducted when the weather is below minima.

An SVS will enable aircraft to maintain a virtual-visual separation from traffic while executing the approach to landing. Part of the virtual-visual component of the SVS is the depiction of traffic not only on a plan-view navigation display (ND), but also on a PFD with terrain, obstacles and weather hazards. This forward-view depiction of traffic, using ADS-B data, would be the virtual-visual view of traffic needed to accept separation responsibility from ATC. Range information would be included with the iconic traffic depiction. To derive the efficiencies associated with a visual approach using visual separation in IMC conditions, the VMC requirements for these approaches to single and parallel runways must be met.

A certain distance or separation must be maintained between aircraft making an approach to landing. This distance is both established and maintained by air traffic control, or the pilot can assume responsibility for separation by accepting a visual approach. Separation is then accomplished according to the pilot's best judgment. In parallel runway operations, a pilot should be able to maintain lateral separation when conducting a visual approach. During IMC, the air traffic controller will ensure that lateral separation is maintained.

During IMC, to continue the approach below the decision height, 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. At 100 feet above the touchdown point, the runway must be visible in order for the pilot to continue the approach to touchdown. Using an autoland system in an autocoupled approach, the pilot performs system checks at prescribed alert heights (AHs) and is able to land in zero/zero visibility.

Any terrain or obstacles that would impinge upon the intended approach must be visible. In addition, runway traffic and runway obstacles should be visible.

A pilot must be able to maintain sufficient path accuracy to make the approach.

2.3.4.1 Single Runway Approach

An SVS equipped aircraft would follow GPS based path guidance depicted on the PFD with a pathway-in-the-sky display. Weather hazards and traffic information are also displayed on both the forward-view PFD and the plan-view ND. Terrain imagery would enhance the flight crew’s situation awareness, and, together with pathway guidance, and EGPWS alerting, supplement the aircraft’s CFIT avoidance capability. If the aircraft is in-trail, separation is maintained using a spacing tool. To perform a visual approach using visual separation in IMC, the pilot would acknowledge seeing the traffic in the PFD. A spacing tool would be used to maintain separation to the touchdown on the runway. Landing in IMC, the PF would use the virtual-visual display for guidance, and visual references of terrain, infrastructure, and the airport. The PFD would also show perspective runway references giving visual cues sufficient (listed above in 3.3.4) to make a virtual-visual landing. 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 too. From this virtual visual capability, an SVS can support pilots in performing Category IIIb approaches without an ILS.

2.3.4.2 Parallel Runway Approaches

Visual approaches to parallel runways closer than 4300ft. using visual separation from adjacent traffic is analogous to virtual-visual approaches in IMC when both aircraft are SVS equipped. Since these approaches are not controlled by conventional ATC radar, it is important that they are supported by additional technology and alerting capability. The flight deck based Airborne Information for

Lateral Spacing (AILS) uses ADS-B information, and a multi-level alerting system with an emergency evasive maneuver to support pilots in keeping each similarly equipped aircraft on its path, and safe from intrusion. An SVS enables *independent* parallel approaches.

Similar to a single runway approach, the pilot would acknowledge seeing the traffic, in this case the parallel traffic, on the front virtual-visual display. Both aircraft would be advised by ATC that separation control had transferred to the cockpits. The same spacing tool used for in-trail spacing would give longitudinal spacing information, while range information would be available from the traffic icon. An AILS system incorporated into an 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 2500ft.

2.3.4.3 Published Visual Approaches

These approaches following terrain features (e.g. DCA river approach) are performed in during VMC. An 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. Similarly, an SVS could help reduce Required Navigational Performance (RNP) minima – especially for IMC approaches to terrain challenged airports. An SVS could 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.

2.3.4.4 Approach Display features

1. The same features as described in departure are also applicable to the approach phase.
2. Display of terrain features such as mountains and hills that are a factor in the progress of the flight.
3. A predictor of the flight path, showing the proximity to terrain features and other obstacles.
4. A guidance display will present an optimal path for the crew.
5. Once the crew accepts the path, there should be in-flight path compliance monitoring and alerting.
6. An alerting capability that warns the pilots of impending collision with terrain based on alerting criteria. It may be similar to current enhanced ground proximity warning capabilities but should include more strategic protection. If alerting features are used, recovery procedures for dealing with alerts must be incorporated.

2.3.4.5 Using the SVS to Avoid CFIT on Approach

The SVS provides a view of the terrain along the path of the aircraft very much as is the case on a clear day. The primary expectation is the pilots flying the aircraft will have a clear-day-like view of terrain and will not fly into a hillside, mountain or other terrain while looking at it in the view provided by an SVS. As a backup, the system will 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. The procedures related to this feature will prescribe a course of action to be taken when warnings are issued. It is anticipated that the warnings will be designed such that appropriate time is available after the warning is triggered to allow a flight to divert its course either by climbing to a higher altitude or deviating around the impending hazard.

2.3.4.6 Using SVS to Prevent RIs on Approach

An SVS can 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 (see Figure 3.2 and ref 4).

2.3.5 SVS Support to Non-normal Operations

An SVS could provide intuitive visual support to pilots in non-normal operations like diversion, missed approach, or emergency situations. SVS applications can include:

- Visual cues for upset recognition and recovery
- En route diversion routing/planning (routing divert or divert to alternate airfield)
- Traffic and weather hazard deconfliction during engine out drift down – provide situation awareness of traffic
- Improved emergency descent awareness of terrain, traffic, (descent caused by engine out, depressurization, smoke/fire)
- Situation awareness for recovery from loss of control
- Depiction of missed approach guidance
- Depiction of emergency approach terrain/obstacle awareness
- Intuitive emergency procedure support/guidanceRecommendations

Current technology supports all-weather en route operations to a high degree. Autopilots can successfully make landings in zero/zero ceiling and RVR; research activities like AILS and paired staggered approaches are presenting ways of making low visibility approach and landings more feasible to a wide range of airports and runway configurations. Because of a slower development, implementation and certification of new technology to assist in low visibility taxi and departure operations, there is a more limited capability in these operations phases than in the approach phase. Consequently, it seems that the two key areas NASA SVS should give added attention to are the taxi and departure phases. This recognizes the fact that a significant advancement in this aspect of low visibility operations at airports would be a very valuable contribution to low visibility operations. Finally, the technology under development in the SVS concept is well suited to addressing this problem.

The next thing that is apparent is that the technology to accomplish zero visibility operations from gate to gate will not become available all at once. It will need to be developed incrementally. Developing capabilities to enable gate-to-gate operations with 0/0 minimums are a longer-range goal than can realistically be met in the remaining time of the AvSP. A feasible approach to accomplishing such an ambitious objective is to incrementally build the technology, as in "block upgrading." With that idea in mind, the first build of an SVS for departure should support operations in reduced visibility, that of Category IIIb or better. This lessens some of the constraints on the initial system, for example, a full-360 degree multi-spectral sensor capability is possible to implement with current technology, but difficult to justify economically to support operations in the rare case of Category IIIc operations. Emergency ground support equipment would have to be equipped for 0/0 operations also and that would be a new direction of SVS research.

2.5 Issues

1. Creating seamless display transitions to best support operational function transitions. For example, how does an SVS best support the pilot during a switch from the head-down to a head-up function?
2. What is the best way to display obstacles and traffic on the departing runway to pilots?
3. Should alerts be incorporated to warn the pilot of obstacles and traffic on the departing runway?
4. If a traffic alert is used, can robust procedures be designed to prevent an intruder incident? This might be a parallel departure or approach situation where one aircraft deviates from its path and poses a threat to the other aircraft. The traffic aircraft could be on a missed approach. One thing to consider in establishing procedures is to not clear an aircraft for takeoff if an aircraft making an approach to an adjacent runway has already declared a missed approach.
5. How will SVS best ensure the separation of aircraft departing from closely spaced parallel runways in low visibility?
6. Can AILS-like systems and procedures be adapted to be applicable in departure operations? How does an SVS detect and warn of intruding traffic and offer escape procedures?

2.6 Reversionary Modes

In the designing of an SVS, fail operational and fail passive capabilities are required to insure flight safety. No single failure can be allowed to cause a flight safety hazard. When systems integrated as parts of SVS begin to fail, the SVS must not present misleading information and make the situation a worse problem for the flight crew to handle. Subsystem redundancies and cross-checking will be required to insure the integrity of flight critical information provided by an SVS. Database integrity is of major concern today – can the terrain and obstacle data be of sufficient integrity to support precision navigation operations? By combining sensor and database information, the required integrity likely will be achieved to support operations down to Category IIIb minima for approach and 300 ft RVR for ground operations and departure.

3 Benefits

An SVS cost benefits study has been completed in a contracted study for NASA (see Appendix C for a more comprehensive analysis). That study identified a number of areas where significant benefits can be achieved using SVS. The conclusions from the study are summarized below with text quoted from the final report from that study.

> 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, we estimated the reduction in arrival and departure delay due of implementing the various SVS capabilities. The analysis results indicate that SVS technologies should provide large economic benefits, but that different capabilities are important at different airports.
>
> 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.

A more detailed discussion of these results is presented in Appendix C that was extracted directly from the final report that discusses the results of the cost benefits study.

These results were very helpful in guiding the development of this CONOPS. They highlight improving departure and arrival minimums, and low visibility ground operations as key areas where SVS can offer operational benefits.

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6 Appendix A – CaB SVS CONOPS Workshop 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) Departures; (3) Ground Operations; and (4) En Route. The first page of each section presents a list of the applications considered broken into the five categories listed above in the previous 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. Three asterisks (***) are placed after the application title when a high priority rating was given to the application.

APPROACH APPLICATIONS

Hazard Avoidance (Non-traffic hazards)

07. Emergency Situations in Challenging Terrain
02. Bird Strikes
10. Hazardous Weather Avoidance
30. Wake Turbulence IMC
24. Terrain Avoidance Equivalent to VMC
25. Terrain Information to Controllers

Self Separation (SS)

06. De-Conflict Approaches
11. Identify Traffic Ahead
21. Self Separation
29. LAHSO
18. Runway Incursions

(*Parallel Approaches)*

03. Closely Spaced
20. Self Contained Parallel Approaches
23. Station Keeping (Parallel approaches)

Emergency Management

27. Upset Recovery
13. Missed Approaches

Improved Operational Capability/Piloting Aids / Enhanced Flight Management

26. Transition from Instruments to Visual Flight
22. Simulation Training Fidelity
19. Runway Remaining
04. CRM HUD/HDD - This one might be more of an issue than an application
15. Potential for Hand Flown Approaches
16. Reduced Minima
17. Reduced Time Arrivals
08. Flare Guidance

Navigation

01. Altitude Deviation
05. Curved Approaches
09. Guidance (symbols)
12. Improved Approaches in Challenging Terrain
14. Path Accuracy / Noise Abatement
28. VASI (Self contained)

Descriptions and Notes

01 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 the glide slope may also be classified as an altitude deviation. One possibility of an SVS application might be to alert the pilots of an altitude deviation. It is not clear that and SVS system would be required to perform this function, however.

02 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.

03, 20, 23 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 Independent 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.

04 CRM HUD/HDD

In this application, the synthetic/enhanced vision system would provide the flying pilot with a Heads Up Display of the extended runway centerline. The nonflying pilot 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.

06 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.

07 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 vision 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.

In this application, information for the database can be obtained from a variety of sources such as the mapping information from the recent shuttle mission, NIMA (for terrain and obstacles), and local area photogrammetry. The potential for using 3D and 4D imagery could also be included in the display information for the application.

08 Flare Guidance

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

09 Guidance (Symbols)

This application addresses the use of synthetic vision to replace or supplement the guidance information currently included in the primary flight display. 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. It is envisioned that pilots would operate similarly to the manner they operate in VMC except that the situation information will be provided by information presented as symbols the display. It is anticipated that the information will be displayed in primary flight display screen, the navigation display screen or in a heads up mode on. 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. It is envisioned that 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, where it would not be a requirement for the approach.

10 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.

11 Identify Traffic Ahead

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

12 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 vision 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.

In this application, information for the database can be obtained from a variety of sources such as the mapping information from the recent shuttle mission, NIMA (for terrain and obstacles), and local area photogrammetry. The potential for using 3D and 4D imagery could also be included in the display information for the application.

13 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.

14 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 primary flight display or a head up display. 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 primary flight display. The vertical guidance would attempt to bring the plane to a location at a specific time at idle thrust.

15 Potential for Hand Flown Approaches

The ability to fly the approach in IMC very much like you would fly the approach in VMC. This includes hand flying the approach and not having to rely solely on instruments or an auto-coupled approach.

16 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 Category II and III approaches the visual reference requirements are even more stringent. With SVS all approaches would be made to the runway without regard to minimums, it would be similar to making an approach in visual conditions.

17 Required Time Arrival

Aircraft flying over inbound fixes at prescribed times. It was thought that this 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.

18 Runway Incursion

This application addresses the problem of one aircraft on the final approach to a runway and a second aircraft, on the ground, taxis 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 air 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 fact 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, its 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 implement, in particular in IMC or VMC. An important consideration in designing this application will be to determine the role of the tower. It is assumed that it would require display of the best available information on both 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)*

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.

20 Parallel Approach see 03

21 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 navigation display and be capable of being followed by the autopilot. The application was given a high priority rating.

22 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 navigation display. 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.

23 Station keeping (see approach application no. 3)

24 Terrain Avoidance equivalent to VMC

This is a central application of SVS. In the words of 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 situational awareness and 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 synthetic vision system could clarify the location of critical terrain features and improve situational awareness. 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 synthetic vision system would also provide sensor detection and display of obstacles (enhanced vision), data link of traffic information and the flight path of the aircraft.

25 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.

26 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.

27 Upset Recovery

The motivation for this application is the knowledge that 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 word 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.

29 Land and Hold Short Operations (LAHSO)

This application would provide graphical overlays of symbology and deceleration factors required for land-and-hold-short operations (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 intuitive tactical picture would 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, etc.

30 Wake Turbulence IMC

In this application the pilots operating it 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. It is not conceivable that such information would be derived purely from a database. It is expected that 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 similarly to how that task is performed in VMC.

It is expected that a means of sensing or predicting the location of potentially hazardous wake turbulence will be used in this application. The AVOSS program at NASA is undertaking such development. 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. It is also conceivable that 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.

DEPARTURE APPLICATIONS

Hazard Avoidance (Non-stationary / non-traffic hazards)
- 01. Weather / Windshear
- 02. Wake Avoidance
- 04. Noise Abatement
- 09. Bird Strikes
- 18. SFO Runway 19

Self Separation and Spacing
- 17. VFR Separation
- 08. Runway/Path Incursion
- 05. Aircraft Separation / Avoidance
- 13. VFR traffic Identification

Emergency management
- 03. Engine Out / Emergency Situations
- 11. RTO

Improved Operational Capability/Piloting Aids / Enhanced Flight Management
- 12. Uncontrolled (feeder/divert) Airports
- 07. Reduced Minima
- 14. Triple and Quard Departures
- 20. Smart Box (Enhanced flight Management)

Navigation
- 06. Terrain Navigation
- 10. Navigation (SIDs)
- 16. Non Standard Go Around
- 19. Airspace Visualization
- 15. Route Depiction

<u>Descriptions and Notes</u>

01 Weather/wind shear
SVS could provide a 3D visualization of severe weather hazards including wind shear. If linked to an airport's wind shear detection radar, SVS could display tactical as well as advisory information.

02 Wake Avoidance ***
The description of this application is the same as that given in A30. The two applications possibly should be combined into a single description such as the on provided in A30. The only point to note is that the application is of increased interest in close parallel approach environments, in the approach case. It potentially has similar interest in the departure environment and could impact the ability of aircraft to depart on closely spaced parallels. This application is very

similar to if not identical to the wake avoidance application of A30. It was given a high priority rating by workshop participants.

03 Engine out/Emergency Situation

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 derived 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 06). 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 be applicable to en route and approach phases.

04 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 primary flight display or a head up display. A synthetic forward view depiction of noise sensitive areas to avoid might be presented. This application is also applicable to the approach phase.

05 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 navigation display 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 instrument flight rules conditions. This application was given a high priority rating by workshop participants.

06 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 12) and en route.

07 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 CAT II, may be used in CAT IIIa conditions. This application was given a high priority rating in some of the workshop groups.

08 Runway/Path Incursion See Approach Application 18

09 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 flocks of bird during airport departure 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 flock would potentially be shown of the SVS display. This would also be a valuable application during approaches.

10 Navigation (SID) ***

Supplement to departure application 6.

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

11 RTO (Rejected Takeoffs)

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 ROT program. The information would be intended to provide improved situation awareness of runway remaining, and other parameters related to completing the takeoff. In additional to showing runway remaining, the information presented could include stopping distance calculations and incorporate related advisory displays.

12 Uncontrolled (feeder/divert) Airports ***

A number of airports do not have an operating control tower. They are referred to as uncontrolled airports. And as the term implies, traffic separation and sequencing is the responsibility of the pilots operating at that airport. Primarily, general aviation aircraft uses uncontrolled airports, but on occasions commercial and business 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. This application was given a high priority rating.

13 VFR traffic identification ***

Traffic information in an SVS could be displayed on the navigation display and as icons in a forward view synthetic depiction of terrain. In visual flight rules (VFR) conditions traffic would be depicted on a cockpit display of traffic information (CDTI) – like navigation display using ADS-B information The increased amount (over TCAS) , accuracy, and frequency of the ADS-B data 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 and was given a high priority rating.

14 Triple and Quad Departures

Some airports have simultaneous departures, either on parallel or diverging routes. When you have more than two departures going out in parallel it becomes very critical if the middle aircraft has some sort of emergency where it has to divert off of its standard path. In all probability it will drift into the path of the other departures creating a hazardous situation.

15 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.

16 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.

17 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 navigation display and be capable of being followed by the auto pilot.

18 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.

EN ROUTE APPLICATIONS

Hazard Avoidance (Non-traffic hazards)
- 04. Weather
- 07. Turbulence
- 15. CFIT (Low altitude en route)

Self Separation and Spacing
- 06. Collision Avoidance
- 14. Traffic Awareness
- 10. Visual Separation
- 12. Station Keeping

Emergency management
- 02. Emergency Descent
- 09. Drift-Down/Emergency Descent
- 13. En route Diversion / Loss-of-Control Recovery

Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management
- 05. Mission Planning/Rehearsal
- 03. Initial Climb/Descent

Navigation
- 11. Oceanic Aircraft Location - ADS-B
- 01. 4D Navigation, En route Optimization
- 08. Special Use Airspace / Airspace Depiction

<u>Descriptions and Notes</u>

01 4D Navigation, En Route Optimization
4D navigaition 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 is this consideration is to be able to be 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.

02 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 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 particular 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 synthetic vision system 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 by coupled with and enhanced ground proximity warning system.

03 In-trail climb and 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.

04 Weather ***

Three dimensional, pictorial depiction of radar and/or dynamically updated real-time data link. Weather information depicted should be prioritized by hazard type and include icing, mountain waves, jet stream awareness, clear air turbulence, etc.

05 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.

06 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.

07 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 15000 feet. Turbulence generated by either of these types can damage aircraft components and equipment.

08 Special Use Airspace[13]/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.

09 Driftdown/emergency Descent ***

Driftdown is the tendency of the aircraft to drift down in altitude. This tendency is greatest over mountainous regions. 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 10000 feet rapidly.

10 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.

11 Oceanic A/C 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.

12 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 navigation display and be capable of being followed by the autopilot.

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[13] Special Use Airspace includes: Alert Areas, Controlled Firing Areas, Military Operating Areas, Prohibited Areas, Restricted Areas, and Warning Areas.

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.

13 En route Diversion or 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.

14 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.

15 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.

In this application, information for the database can be obtained from a variety of sources such as the mapping information from the recent shuttle mission, NIMA (for terrain and obstacles), and local area photogrammetry. The potential for using 3D and 4D imagery could also be included in the display information for the application.

GROUND OPERATIONS APPLICATIONS

Hazard Avoidance (Non-traffic hazards)
08. Obstacle Avoidance
01. Aircraft Clearance Awareness
02. Deicing Station
03. Gates

Self Separation and Spacing
12. Runway Incursion
13. Runway Incursion Detection and Accident Prevention

Emergency management
11. RTO
15. SVS on Emergency Vehicles

Extended or Improved Operational Capability Piloting Aids / Enhanced Flight Management
07. Mission Rehearsal
04. Ground Equipage for CAT IIIC
10. Rollout/Runway Based Queues
18. Turn Off and Hold Short
14. Speed Awareness
06. Language Barriers

Navigation
16. Taxi Guidance in Low Visibility
09. Precision Control
05. High Visibility Taxi Guidance
17. Taxiway Excursions

Descriptions and Notes

01 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.

02 Deicing 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 the correct runway, and to 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.

03 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.

04 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 runway visual range (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.

06 Language Barriers (similar to ground operation application 01)

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.

07 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).

08 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.

09 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, ever 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.

10 Rollout/runway 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, Langley Research Center has conducted research in this technology (see Ref 4).

11 RTO (Rejected Takeoffs)
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 ROT program. The information would be intended to provide improved situation awareness of runway remaining, and other parameters related to completing the takeoff. In additional to showing runway remaining, the information presented could include stopping distance calculations and incorporate related advisory displays.

12, 13 Runway Incursions *** See Approach application 18.

14 Speed Awareness
After landing, an airplane must be brought under control in order to safely turn off onto a runway exit. Exiting sooner decreases runway occupancy time. 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 his actions. The position and speed information might be superimposed on a synthetic runway display. Speed guidance to the “next” exit might be provided in addition.

15 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 head down display. In conditions of limited visibility the guidance might additionally be displayed tactical cues on a head-up display with a synthetic image of the forward view of the airport. Enhanced vision sensors might provide position information of dynamic obstacles.

18 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.

7 Appendix B -- Visibility Categories

ILS Minimums (with all required ground and airborne systems components operative)

	DH (feet)	RVR (feet)
• 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 7.1 Visibility Categories

Figure 7.1 depicts the published ILS (approach) minima. Specific approach procedures often require the use of a higher decision height and/or runway visibility range (RVR) and are according to: Part 91.189. Equipage is according to Appendix A to Part 91.

8 Appendix C – Operational Benefit Analysis (Review of Results and CONOPS Recommendations)

The discussion in this section is reproduced from the report from an LMI cost benefits study sponsored by NASA.

This is a review of the results of the analysis and their implications for the synthetic vision system (SVS) concept of operations (CONOPS).

8.1 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 (ROT) 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.

8.2 Reduced Runway Occupancy Time

Runway occupancy times (ROTs) are estimated to increase 20% with low visibility, wet conditions. The NASA Roll-Out and Turn-Off (ROTO) technologies that are included with SV2 and SV3 are assumed to eliminate the 20% penalty. With SV2, runway occupancy time (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.

8.3 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.

8.4 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 10 airports have CAT IIIb runways including 2 with 300 foot RVR capability.

8.5 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 feet RVR, while SV2 and SV3 extend down to 300 feet RVR.

8.6 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.

8.7 Independent Arrivals on Closely Spaced Parallel Runways

The NASA Airborne Information for Lateral Spacing (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 8-1. 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 then 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.[14]

[14] 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 8-1. 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

8.8 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 (T-NASA) 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.

8.9 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 8-2 contains a hypothetical list of hardware for each technology implementation.

Table 8-2. 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 Sensor	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™*

8.10 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 (CONOPS) 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 be included in SVS testing.

- Tests and simulations to demonstrate the ability to safely conduct converging and circling operations in IFR CAT IIIb conditions.

- Tests and simulations to demonstrate 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.

- Tests and simulations to demonstrate the ability to conduct ground operations at visual flight rule (VFR) tempos with visibility as low as 300 feet.

- Tests and simulations to demonstrate, as a minimum, the ability to conduct arrival and departure operations under conditions of 0 foot ceiling and 300 foot runway visual range (RVR) with a goal of demonstrating operations at 0 foot RVR.

- Tests and analysis to determine 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.