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Synthetic Vision

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16.1 Introduction

A large majority of the avionics systems introduced since the early days of flight (attitude indicators, radio navigation, instrument landing systems, etc.) have sought to overcome the issues resulting from limited visibility. Limited visibility is the single most critical factor affecting both the safety and capacity of worldwide aviation operations. In commercial aviation, over 30% of all fatal accidents worldwide are categorized as Controlled Flight Into Terrain (CFIT)—accidents in which a functioning aircraft impacts terrain or obstacles that the flight crew could not see. In general aviation, the largest accident category is Continued Flight into Instrument Meteorological Conditions, in which pilots with little experience continue to fly into deteriorating weather and visibility conditions and either collide with unexpected terrain or lose control of the vehicle because of the lack of familiar external cues. Finally, the single largest factor causing airport flight delays is the limited runway capacity and increased air traffic separation distances resulting when visibility conditions fall below visual flight rule operations. Now, synthetic vision technology will allow this *visibility* problem to be solved with a *visibility* solution, making every flight the equivalent of a clear daylight operation.

Initial attempts to solve the visibility problem with a visibility solution have used imaging sensors to enhance the pilot's view of the outside world. Such systems are termed "enhanced vision systems," which attempt to improve visual acquisition by enhancing significant components of the real-world scene. Enhanced vision systems typically use advanced sensors to penetrate weather phenomena such as darkness, fog, haze, rain, and/or snow, and the resulting enhanced scene is presented on a head up display (HUD), through which the outside real world may be visible. The sensor technologies involved include either active or passive radar or infrared systems of varying frequencies. These systems have been the subject of experiments for over two decades, and the military has successfully deployed various implementations. However, no sensor-based application has seen commercial aircraft success for a variety of reasons, including cost, complexity, and technical performance. Though technology advances are making radar and infrared sensors more affordable, they still suffer from deficiencies for commercial applications. High-frequency radars (e.g., 94 GHz) and infrared sensors have degraded range performance in heavy rain and certain fog types. Low-frequency (e.g., 9.6 GHz) and mid-frequency (e.g., 35 GHz) radars have improved range, but poor resolution displays. Active radar sensors also suffer from mutual interference issues with multiple users in close proximity. All such sensors yield only monochrome displays with potentially misleading visual artifacts in certain temperature or radar reflective environments.

A "synthetic vision system" is a display system in which the view of the outside world is provided by melding computer-generated airport scenes from on-board databases and flight display symbologies, with information derived from a weather-penetrating sensor (e.g., information from runway edge detection or object detection algorithms) or with actual imagery from such a sensor. These systems are characterized by their ability to represent, in an intuitive manner, the visual information and cues that a flight crew would have in daylight — Visual Meteorological Conditions (VMC). The visual information and cues are depicted based on precise positioning information relative to an onboard terrain database, and possibly includes traffic information from surveillance sources (such as TCAS, ASDE, etc.) and other hazard information (such as wind shear).

Synthetic vision displays are unlimited in range, unaffected by atmospheric conditions, and require only precise ownship location and readily available display media, computer memory, and processing to function. The rapid emergence of reliable GPS position information and precise digital terrain maps, including data from the Space Shuttle Radar Topography Mission (SRTM), make this approach capable of both true all-weather performance as well as extremely low cost, low maintenance operations. When fully implemented, successful synthetic vision technologies will be a revolutionary improvement in aviation safety and utility.

16.2 Background

Synthetic vision systems are intended to reduce accidents by improving a pilot's situation and spatial awareness during low-visibility conditions, including night and Instrument Meteorological Conditions (IMC). Synthetic vision technologies are most likely to help reduce the following types of accidents: CFIT, Loss of Control, and Runway Incursion (RI). CFIT is the number one cause of fatalities in revenue service flights, and the majority of CFIT accidents, runway incursion accidents, and GA loss of control accidents can be considered to be visibility-induced crew error, where better pilot vision would have been a substantial mitigating factor. Better pilot vision is provided by synthetic/enhanced vision display systems. These technologies will serve as a substantial mitigating factor for aircraft accidents of other types as well. Such display systems will substantially reduce the following accident precursors:

- Loss of vertical and lateral spatial awareness.
- Loss of terrain and traffic awareness on approach.
- Unclear escape or go-around path even after recognition of problem.
- Loss of attitude awareness.
- Loss of situation awareness relating to the runway environment.
- Unclear path guidance on the surface.

Many laboratory research efforts have investigated replacing the conventional attitude direction indicator or primary flight display for transport airplanes with a pictorial display to increase situation awareness as well as to increase operational capability for landing in low-visibility weather conditions. These research efforts have consistently demonstrated the advantages of pictorial displays over conventional display formats, and the technologies involved in implementing such concepts appear to become available in the near term. Over the past 5 years, a number of organizations have demonstrated synthetic vision-based flight, landings, and taxi operations in research aircraft. Digital data links and displays of the positions and paths of airborne and ground traffic have also been demonstrated.

The practical implementation tasks remaining are to define requirements for display configurations and associated human performance criteria, and to resolve human performance and technology issues relating to the development of synthetic vision concepts. These same tasks remain as well for the necessary enabling technologies and the supporting infrastructure and certification strategies. Aggressive, active participation by synthetic vision advocates with appropriate standards and regulatory groups is also required.

16.3 Applications

All aircraft categories are expected to benefit from synthetic vision applications, including general aviation aircraft, rotorcraft, business jets, and commercial transports (both cargo and passenger). The concepts will emphasize the cost-effective use of synthetic/enhanced vision displays, worldwide navigation, terrain, obstruction, and airport databases, and Global Positioning System (GPS)-derived navigation to eliminate "visibility-induced" (lack of visibility) errors for all aircraft categories.

The high-end general aviation aircraft (business jets) and commercial transports application of synthetic vision will prevent CFIT and Runway Incursion (RI) accidents by improving the pilot's situation awareness of terrain, obstacle, and airport surface operations during all phases of flight, with particular emphasis on the approach and landing phases, airport surface navigation, and missed approaches. Current accident data indicate that the majority of CFIT accidents involving transports occur during non-precision approaches. This application will require the examination of technology issues related to implementation of an infrastructure for autonomous precision guidance systems. The standards committees (RTCA SC-193 and EUROCAE WG-44) that are developing requirements for terrain, obstacles, and airport surface databases and maintaining coordination with the Federal Aviation Administration's (FAA) Local Area Augmentation System (LAAS) and Wide Area Augmentation System (WAAS) programs, are aware of synthetic vision applications.

In the U.S., runway incursions have increased an average of 15% each year for the last 4 years. Worldwide, the only airline fatalities from 1987 to 1996 due to runway incursions occurred in the U.S. A runway incursion occurs any time a plane, vehicle, person or object on the ground creates a collision hazard with an airplane that is taking off or landing at an airport under the supervision of air traffic controllers. The FAA has established the Runway Incursion Reduction Program (RIRP) to develop surface technology at major airports to help reduce runway incursions. Future activities are planned by NASA with the FAA to integrate the RIRP surface infrastructure with the flight deck to enhance situation awareness of the airport surface and further reduce the possibility of runway incursions. Runway incursion reduction efforts will target surface surveillance, GPS-based navigation, and Cockpit Display of Traffic Information (CDTI) to improve situational awareness on the surface. Also to be considered are surface route clearance methodologies and onboard alerting strategies during surface operations (runway incursion, route deviation, and hazard detection alerting).

The application of synthetic vision to low-end general aviation (GA) aircraft will advance technologies to prevent GA CFIT and loss-of-control accidents by improving the pilot's situation awareness during up and away flight. Current accident data indicate a leading cause for GA loss-of-control accidents are due to pilot disorientation after inadvertent flight into low-visibility weather conditions. A low-cost synthetic vision display system for the low-end general aviation aircraft, which often operate in marginal VMC, will enable safe landing or transit to VMC in the event of the unplanned, inadvertent encounter of IMC, including low-ceiling and low-visibility weather conditions. It will also address loss of spatial situation awareness and unusual attitude issues. Successful synthetic vision concepts will also lower the workload and increase the safety of the demanding single-pilot GA IFR operations.

Synthetic vision applications to rotorcraft will be forced to supplement the database view of the outside world with a heavier dependence on imaging sensors, because the rotorcraft environment has requirements that exceed the current expectations for the content of available databases. For example, emergency medical service vehicles operate to and from innumerable ball fields and hospitals, and at very low altitudes amongst power and telephone wires. Hence rotorcraft applications will employ more of the features of enhanced vision, although low-cost imaging sensors for civilian applications will present significant challenges.

16.4 Concepts

Synthetic vision systems are based on precise ownship positioning information relative to an onboard terrain database, and traffic information from surveillance sources (such as TCAS, ADS-B, or TIS-B, air-to-air modes of the weather radar, ASDE, AMASS, etc.). Enhanced vision systems are based on display presentations of onboard weather-penetrating sensor data combined with some synthetic vision elements.

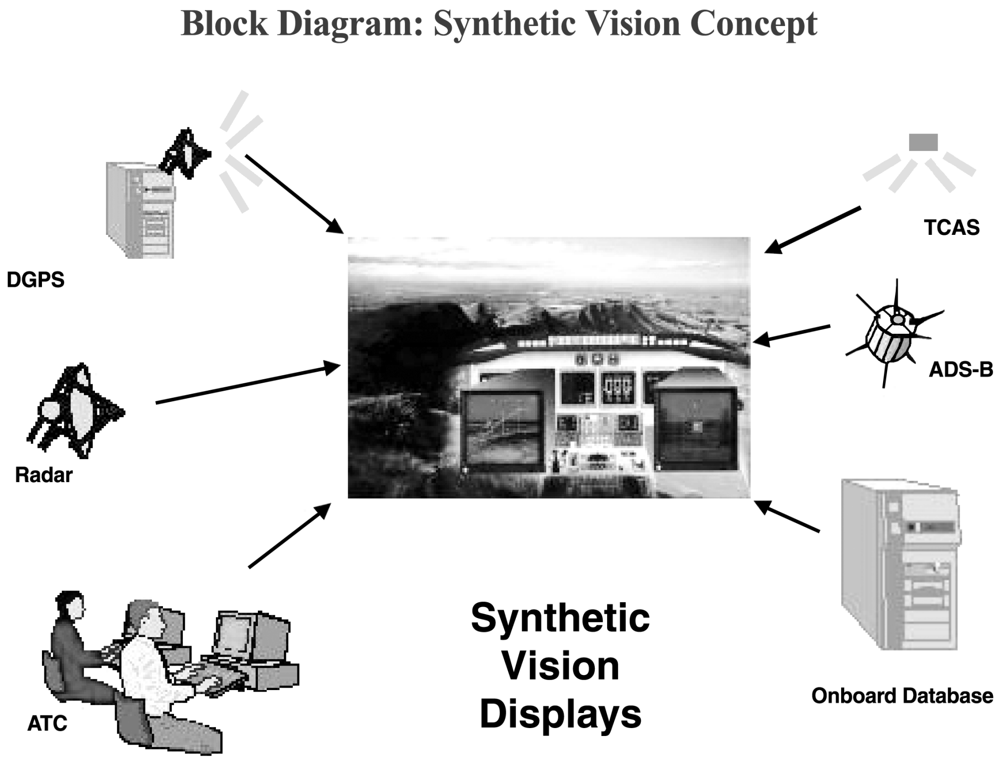

FIGURE 16.1 Possible synthetic vision system.

Figure 16.1 illustrates a top-level view of a potential high-end synthetic vision system. The specific architecture, and use of specific technology, is for illustration only. In this flight operations concept, the traffic surveillance sources of information are represented, as are the other enabling technologies of terrain/obstacle/airport databases (including curvilinear approach waypoint data), data link, and DGPS/LAAS/WAAS. Surface operations sources of surveillance information could be ASDE/AMASS (via TIS-B) or ADS-B. Controller Pilot Datalink Communications (CPDLC) may also be considered.

These system concepts address information conveyance for two separate functional levels:, tactical and strategic. Tactical concepts generally provide alerting information and may include escape guidance methodologies, while strategic concepts are more concerned with incident prevention/avoidance. These display concepts allow for presentation of three-dimensional perspective scenes with necessary and sufficient information and realism to be nearly equivalent to daylight VMC, thus increasing spatial awareness (terrain, attitude, and traffic). Symbolic information can be overlaid on these scenes to enhance situational awareness through, for example, presentation of an artificial horizon, heading, attitude indications, and pitch and/or velocity vector references. Tactical guidance capability can also be provided by highway or pathway-in-the-sky symbology for approach and landing, departure, and go-around, or other ATC-cleared routings.

16.5 Challenges

Of the technologies and issues involved in the cost-effective use of synthetic/enhanced vision displays, worldwide navigation, terrain, obstacle, and airport databases, and GPS-derived navigation to eliminate visibility-induced errors, challenges exist in the areas of human factors, avionics displays, DGPS, certification, and databases.

As with any new avionics concept, the important principles of human-centered design and other human factors considerations must be applied, as human error is a principal cause of aircraft accidents of any type. A majority of CFIT and approach, landing, takeoff, and runway incursion accidents have been attributed to visibility-induced crew error. Pilot situation and spatial awareness should be dramatically improved by synthetic vision display systems, and the maturity of the human factors discipline is such that effective designs can be confidently expected.

For avionics applications, the most significant display technology issues that have the potential for limiting the implementation of synthetic vision are

- Limited cockpit space available for display media
- Limited display capability (graphics, size, field of view, brightness, color) of current commercial aircraft
- Retrofit cost

The tactical (PFD) and strategic (Nav Display) pictorial concepts may be presented on existing form factor A, B, or D displays in a retrofit application. However, as larger displays may be more effective in presenting these concepts, other form factors will be considered for new cockpits. Other display mechanisms, such as HUDs or head-mounted systems, are not illustrated in Figure 16.1 but will be investigated. Expectations for display solutions are

- Panel-mounted for near-term applications in modern "glass" flight decks
- Head-up displays for retrofit to older "steam gauge" flight decks
- Head-mounted (and head-tracked for unlimited field-of-view) or direct in-window displays for future applications
- All display types would have guidance and other flight symbology superimposed on the terrain image

Another important enabling technology for synthetic vision systems is the DGPS infrastructure. It is anticipated that unaugmented civil-code GPS will be suitable for en route operations, and that the FAA's WAAS and/or LAAS is required for approach and landing (meter/submeter accuracy). The intent in this arena for synthetic vision system enthusiasts is to support, supplement, and complement research and modernization work currently underway by the FAA, NASA, and other governmental and private entities around the world to implement LAAS/WAAS and other precision positioning systems.

Implementation issues such as cost-effectiveness and certification, however, provide perhaps the greatest challenges to full realization of commercially viable synthetic vision systems. The successful development of a compelling business case to serve as an economic incentive over and above the safety benefits of a synthetic vision system is a significant hurdle. The leading candidate for that business case is increased operational capability in low-visibility conditions. Tactical use of synthetic vision as a replacement for today's PFD requires the certification of a flight-critical system. While certification to that level is a lengthy and expensive process, that effort is beginning. Also needed are solid, certifiable processes for database development assurance, quality assurance, and integrity assurance, and standards for the database content sources and maintenance. Efforts are also underway in this area.

Database implementation issues are equally challenging. However, the recent formulation of the joint RTCA/EUROCAE committee to develop the industry requirements for terrain, obstacle, and airport databases, indicates a desire by the world aeronautical community to solve the database issues. In line with this activity is the FAA's Notice of Proposed Rulemaking (NPRM) requiring all airplanes with turbine engines and six or more passenger seats to carry a TAWS using a computer database for providing terrain displays and warnings. To carry such technology beyond the terrain warning stage to applications of strategic planning and tactical navigation and guidance, however, compounds the database implementation issues. The most significant are

- Cost and validation of accurate high-resolution worldwide terrain, obstacle, and airport databases ($50 million by some estimates)
- Liability, maintenance, and ownership of the data

It seems clear the database implementation issues will require not only involvement of the appropriate American government agencies (FAA, NASA, NOAA, NIMA), but also ICAO and member governments' funding and sponsorship.

The capability of synthetic vision systems is limited only by the resolution and accuracy of the terrain database. Two key potential concerns with a synthetic vision approach and their mitigation strategies are as follows:

1. "How can you trust the database is correct?"
   - The terrain database will be certified to necessary standards at the start. Aircraft operations (cruise flight, approach, landing, taxi) will only be allowable to the certified fidelity of the database.
   - It will constantly improve over time. (Every clear daytime approach will be confirmation of the basic presentation.)
   - If necessary, processing of radar altimeter or existing weather radar signals may be used to "confirm" the actual terrain surface with the displayed database in real time.
   - Flight guidance cues used by the flight crew will come from the same GPS positioning as will be certifiably acceptable for instrument-only (no synthetic vision) approaches.
2. "What about obstacles or traffic that are not in the database?"
   - Airborne and ground traffic position information data-linked to the aircraft would be readily displayed
   - The proper flight path — always clear of buildings and towers — would be clearly displayed and obvious to follow.
   - The database would be updated on a regular cycle, much like today's paper approach charts.
   - Such obstacles and/or traffic are, of course, not able to be seen in today's nonsynthetic vision, low-visibility operations.
   - If necessary, additional modes may be added to the onboard weather radar to detect obstacles and traffic not in the database.
   - If necessary, imaging sensors may be added to augment the synthetic scene.

The *approximate* requirements for the database, "nested" in four layers of resolution, for example, are as follows:

Location from Airport Spacing (m)	Resolution (m)	Accuracy (m)	Grid
30 miles—Enroute	~150	~50	~500
30 − 5 miles — Approach/Departure	~50	~30	~200
5 − 0.5 miles — Landing/Takeoff	~10	~5	~50
0 miles — Surface Ops	~0.5	~1	NA
For comparison:			
Shuttle SRTM	20	8–16	30

The realization of such a database and its supporting infrastructure is somewhat dependent on the following:

- The shuttle radar topography mapping mission is expected to provide more than adequate terrain data for the enroute and approach/departure databases for approximately 80% of the earth's surface.
- The support of the National Imagery and Mapping Agency (NIMA) is considered critical for developing and releasing the worldwide enroute and approach/departure level data. International defense/security issues may limit the release of higher-resolution data.

- Local airport authorities and/or other providers (not the government) are expected to develop the landing/takeoff and surface ops databases to specified certification standards for individual airports. The safety and operational benefits to be gained by adding an airport to the evolving database are expected to be a significant motivation.

16.6 Conclusion

Synthetic vision display concepts allow for presentation of three-dimensional perspective scenes with necessary and sufficient information and realism to be equivalent to a bright, clear, sunny day, regardless of the outside weather condition, for increased spatial awareness (terrain, attitude, and traffic). Symbolic information can be overlaid on these scenes to enhance situational awareness and to provide tactical guidance capability through, for example, presentation of pathway-in-the-sky symbology. In spite of the numerous challenges and hurdles to be faced and overcome to prove synthetic vision applications practical, not just as a research demonstration, but as a viable, implementable capability, the technologies are available in the near term and the safety and operational benefits seem obvious. Solving a *visibility* problem with a *visibility* solution just plain makes sense. There is little doubt that synthetic vision-based flight *will be* the standard method for low-visibility operations in the near future.

Defining Terms

ADS-B	Automated Dependent Surveillance-Broadcast
AMASS	Airport Movement Area Safety System
ASDE	Airport Surface Detection Equipment
ATC	Air Traffic Control
CDTI	Cockpit Display of Traffic Information
CFIT	Controlled Flight into Terrain
CPDLC	Controller Pilot Datalink Communications
DGPS	Differential Global Positioning System
EuroCAE	European Organisation for Civil Aviation Equipment
FAA	Federal Aviation Administration
GA	General Aviation
GHz	Gigahertz
GPS	Global Positioning System
HUD	Head-Up Display
IFR	Instrument Flight Rules
IMC	Instrument Meteorological Conditions
LAAS	Local Area Augmentation System
NASA	National Aeronautics and Space Administration
Nav	Navigation
NIMA	National Imagery and Mapping Agency
NOAA	National Oceanic and Atmospheric Administration
NPRM	Notice of Proposed Rulemaking
PFD	Primary Flight Display
RI	Runway Incursion
RIRP	Runway Incursion Reduction Program
RTCA	Requirements and Technical Concepts for Aviation
SC	Special Committee
SRTM	Space Shuttle Radar Topography Mission
TAWS	Terrain Awareness Warning Systems
TCAS	Traffic Alert and Collision Avoidance System
TIS-B	Traffic Information Services — Broadcast

U.S.	United States
VMC	Visual Meteorological Conditions
WAAS	Wide Area Augmentation System
WG	Working Group

Further Information

NASA's Aviation Safety Program, Synthetic Vision Project: http://avsp.larc.nasa.gov/