PRECISION APPROACHES FOR THE YEAR 2000

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ABSTRACT

The terminal area in the year 2000 will be congested, with an increased focus on efficiency. Weather is and will continue to be a major delay factor.

The current precision approach system, the Instrument Landing System (ILS), contributes to weather delays because it provides little design flexibility in approach procedures, and in some cases cannot be sited at all. New precision approach technologies can alleviate these problems. Proposed precision approach systems for the year 2000 are ILS supplemented by Area Navigation (ILS/RNAV), the Microwave Landing System (MLS), the Global Navigation Satellite System (GNSS), and Synthetic Vision Systems (SVS).

This paper evaluates the ability of these four alternative precision approach systems to meet terminal area requirements in the year 2000.

INTRODUCTION

Many of today's air traffic control terminal areas are operating at near capacity, creating an environment in which even slight disruptions create significant delays. There are several reasons for delays: Adverse weather, excessive traffic volume, and terminal area facility constraints.

The FAA projects that the terminal area will become even more congested by the year 2000, due to ever increasing user demand. When weather conditions deteriorate, separation can no longer be effected visually. Instead, the pilot must guide the aircraft to a safe landing using aircraft instrumentation that receives navigation signals from ground equipment. This operation, conducted according to Instrument Flight Rules (IFR), constrains the air traffic control system because it increases air traffic controller workload, necessitates additional ATC procedures, and is subject to the inherent limitations of the ground and airborne equipment. Limitations in current precision approach technology contribute significantly to weather delays.

This paper analyzes the requirements for the future precision landing system for the year 2000. The role of ILS/RNAV, MLS, GNSS, and SVS is evaluated.

THE PROBLEM

In 1990, more than 392,000 aircraft were delayed by more than 15 minutes. These delays are estimated to have cost the U.S. airline industry in excess of $2 billion dollars. More than half of the delays in the United States are caused by weather.[1]

During Visual Meteorological Conditions (VMC), pilots maintain visual separation from other aircraft, see the runway, and land. During Instrument Meteorological Conditions (IMC)-- weather conditions during which pilots can no longer see one another, or the runway, at acceptable distances-- IFR is imposed. Under IFR, several constraints exist that are not present during Visual Flight Rules (VFR). These constraints include:

- **Air Traffic Procedures.** Aircraft may only approach on published instrument approach procedures; ground movements are restricted due to protection of ILS critical areas; and ATC workload is increased as the controller retains responsibility for aircraft separation throughout the approach.
- **Aircraft Technical Requirements.** Aircraft must have appropriate certified avionics equipment.
- **Ground Equipment Requirements.** Appropriate ground equipment must be available, including navigation transmitters, approach and runway lighting, and weather detection and reporting capability.

The capabilities of the precision approach system in use can significantly affect these constraints.

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THE CURRENT PRECISION APPROACH SYSTEM

Currently, precision approach guidance is provided by ILS. ILS contributes to the constraints described above in the following ways:

- Procedurally, ILS limits aircraft to long straight-in final approaches (7+ miles), creating potential airspace conflicts in multi airport environments, and constraining the number of approach paths that can be provided. Each ILS provides only one approach path.

- The ILS guidance signal is formed by a direct and ground reflected signal requiring a significant level of site preparation. ILS can only be installed at locations where site preparation is practical.

- ILS is limited to 40 frequency channels constraining the number of sites that can be allocated a frequency in a given geographical area. In addition, the ILS frequency band suffers from interference from adjacent band high power FM radio transmitters.

- ILS is sensitive to signal diffraction and blockages caused by ground traffic, necessitating the use of large protected areas on the airport surface (critical areas).

ILS was adopted by the International Civil Aviation Organization (ICAO) as the precision approach standard in the 1940's. The ATC environment at that time was considerably less congested than today, and ILS provided the required service. Due to traffic increases, the emphasis is on efficiency and increased capacity in today's environment.

Based on the needs of the future environment, requirements have been identified that are beyond the capabilities of ILS. These requirements will of necessity become even more sophisticated to meet the needs of the 21st century. The following sections discuss these requirements and the ability to achieve them with different precision approach systems.

PRECISION APPROACH REQUIREMENTS

In the U.S., the requirements for precision approaches are determined by the FAA. The FAA standards are based on various national and international standards, including those developed by the Radio Technical Commission for Aeronautics (RTCA) and ICAO. The standards cover all aspects of precision approach systems, including operation and maintenance of both ground and airborne equipment.

In many ways, precision approach requirements have grown up around the existing infrastructure and equipment. When ICAO developed the first international standards for precision landing systems, they were based on the available ILS technology. For example, standards were designed around a 7+ mile straight-in final approach because that was the type of procedure that ILS supported.

As traffic levels increased, new requirements that were beyond the capabilities of ILS were identified. In the 1970's, ICAO identified 38 operational requirements for a precision approach system.[2] These 38 requirements constitute the most current description of precision approach needs for the 21st century.

The 38 requirements cover a wide range of characteristics, from flight inspection periodicity to service volume. Several of the requirements can be used to alleviate or mitigate constraints in the terminal area environment.

The 38 ICAO requirements can be synthesized into four main areas as shown in Exhibit 1.

1	Precise position information to enable computed guidance for advanced operations
2	Wide area coverage to facilitate efficient transition between phases of flight
3	Capability to provide service at all required locations
4	Operation unaffected by weather

Exhibit 1. Precision Approach System Requirements

Precise position information will enable computed guidance for advanced procedures including computed centerline, curved approach tracks and multiple descent paths. It will permit aircraft to conduct instrument procedures similar to those flown during visual conditions. Use of advanced procedures will improve traffic flow in congested terminal areas through the use of curved approaches with straight-in final segment lengths of 1.5 to 3 NM.

Wider area coverage will facilitate efficient transition from en route to terminal phases of flight. Efficient transition procedures could eliminate the need for ATC radar vectors. Wide area coverage ensures that aircraft conducting curved approaches receive precision approach guidance signals at all times, including the initial portion of the approach.

The capability to provide service at all required locations encompasses requirements for adequate channel capacity, ease in equipment siting, and signal interference immunity. Today, over 1400 runways qualify for precision approach systems, yet fewer than 900 are equipped. By the year 2000, approximately 2000 runways are projected to qualify for precision approach systems.[3] To satisfy demand, provision of service at all required locations must be practical.

A critical aspect of improving capacity will be to provide more efficient use of runways during IFR weather conditions. CAT I, II or III performance at any location that demonstrates adequate need must be practical. CAT II/III capability will be required at most major airports and at those airports with a high incidence of adverse weather. A recent study concluded that, of the 2000 runways qualifying for precision approach systems, over 500 may meet the requirements for CAT II/III facilities by the end of the decade.[4]

CANDIDATE PRECISION APPROACH SYSTEMS FOR THE YEAR 2000

Available and emerging technologies that are candidates to support precision approaches in the year 2000 are:

- ILS Augmented by Area Navigation
- Microwave Landing Systems
- Global Navigation Satellite Systems
- Synthetic/Enhanced Vision Systems

The capability of each system to satisfy the four requirements for a precision landing system in 2000 is discussed below:

Instrument Landing Systems

ILS is the primary precision approach guidance system currently approved for domestic and international use. Although the operation of ILS has improved over the years in areas such as antenna design, reliability, and performance, ILS satisfies only 12 of the 38 requirements identified for the precision approach system of the future.

Some airlines have proposed using ILS with RNAV to perform curved path approaches. A major U.S. carrier has conducted trials using RNAV/ILS and has flown curved approaches to an ILS final using a B-757 equipped with an RNAV system.[5] Results indicate that curved approaches can be flown using RNAV/ILS. However, the technique may have both limited capability and applicability.

Requirement 1. Precise position information.

It is possible to perform curved approaches using RNAV guidance, transitioning to ILS for the straight-in final approach segment. Tests conducted at the FAA Technical Center in August 1990 indicate that, to consistently transition from RNAV to ILS guidance, the straight final segments should not be shorter than 3.9 to 5.5 NM, depending upon the type of procedure employed.[6]

RNAV/ILS approaches represent a new method of using the current ILS capability. However, RNAV accuracy limitations will not permit curves with short straight-in final segments (1.5 to 3 NM), and will not fully satisfy requirement 1.

Requirement 2. Wide area coverage.

The ILS service volume is narrow, the glide slope is limited to 4500 feet in altitude, and the localizer to 15 NM range. Only a single precision glide path and approach track is provided.

Because RNAV is a computer that relies on inputs from several navigation sensors, its ability to determine position and the accuracy of the position determination depends on the type, number, and location of aids available. Generally, navigation aids are available to provide adequate coverage for RNAV/ILS operations.

Requirement 3. Capability to provide service at all required locations.

The number of operating channels available in the ILS frequency band is limited to 40 and localizer signals are susceptible to adjacent band radio frequency interference. Increases in the number of ILS installations is inhibited by frequency congestion and interference. Also, at certain locations ILS can be difficult or impossible to site due to terrain and real estate restrictions. Due to these problems, fewer than half of the currently identified requirements for new precision approaches in areas with high runway densities can be satisfied with ILS.[7]

Requirement 4. Operation unaffected by weather.

Glide slope operation is susceptible to changes in the weather (e.g., snow accumulation can cause a change in the ground plane affecting the reflected signal). RNAV/ILS can support CAT II/III straight-in approaches but with the attendant ILS limitations. Provision of a higher category of service at existing sites is often prohibitive due to site preparation costs.

Microwave Landing Systems

MLS was designed to fulfill a fundamental role in the terminal area environment in the year 2000 and beyond. It has been approved as the Precision Approach system of the future by ICAO, and was designed to meet all 38 operational requirements identified in 1972. MLS satisfies all four requirement areas identified as follows.[8]

Requirement 1. Precise position information.

MLS will support curved approaches with straight final segment lengths as short as 1.5 NM. Procedures based on this capability will provide for more flexible and efficient approach and landing operations. Exhibits 2, 3, and 4 show an example of the effect of IFR under certain runway conditions at New York area airports. Under VFR (Exhibit 2), air traffic flow is optimum and each airport operates independently of traffic arriving and departing at neighboring airports. During IFR (Exhibit 3), when approaches are made using ILS, aircraft land using long straight-in approaches (7+ NM). When this occurs and Runway 13 is used for landing at La Guardia, Teterboro Airport is virtually closed due to airspace conflicts. Additionally, some runways are not usable as they are not equipped with ILS. MLS operations eliminate the rigidity of long straight-in approaches during IFR and effectively emulate VFR operations (Exhibit 4).

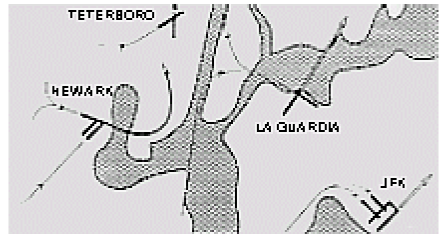

Exhibit 2. New York Terminal Area in VFR

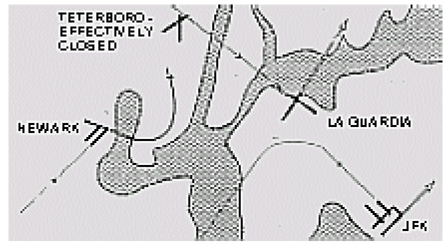

Exhibit 3. New York Terminal Area ILS Operations

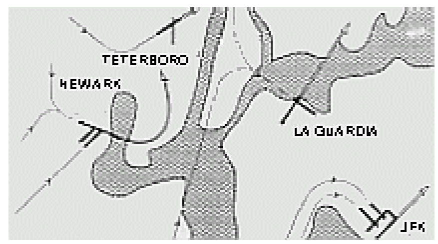

Exhibit 4. New York Terminal Area MLS Operations

Requirement 2. Wide area coverage.

MLS provides precision approach guidance relative to the runway threshold up to ±60 degrees lateral coverage, up to 15 degrees vertical coverage to an altitude of 20,000 feet, and to a range of 20 NM. Guidance throughout this volume allows an aircraft to precisely transition from the en route phase of flight to the final approach without radar vectors. The elevation station is capable of supporting glide paths up to 15 degrees above the horizontal.

Requirement 3. Capability to provide service at all required locations.

MLS has 200 channels allocated in the microwave frequency band to avoid channel congestion and interference problems. MLS can be sited in almost any terrain. Therefore, MLS can be installed on currently uninstrumentable runways, leading to an increase in the number of available precision approach runways and more efficient operations during IMC.

Requirement 4. Operation unaffected by weather.

MLS is virtually unaffected by changing weather conditions, providing accurate and stable guidance signals at all times. MLS installations satisfy CAT III guidance accuracy requirements. The category of service provided will be determined by the operational requirements at the specific location.

Global Navigation Satellite System

GNSS refers to a satellite-based navigation system, currently described by the aviation community as including the United States' Global Positioning System (GPS) and the Soviet Global Orbital Navigation Satellite System (GLONASS), or an integrated version of both (GPS/GLONASS) to perform a range of navigation functions.

The GNSS is widely expected to have a major impact on aircraft operations for oceanic, en route and terminal area navigation, including a non-precision approach capability.

Use of Satellite-based systems for precision approach represents an entirely new concept in terms of standards development. Existing standards were developed for ground-based precision approach systems and there are no standards for precision approaches using satellite technology. Therefore, it is difficult to determine if GNSS can achieve the accuracy, availability, and integrity to support precision approaches.

Standards development for satellite navigation is underway. The majority of this work is associated with en route navigation. Efforts to evaluate satellite-based precision approach capabilities are based on current ILS/MLS standards.

Study results indicate that the following issues must be resolved before GNSS can be used for precision approach:

- Availability. The GPS constellation must be enhanced with a considerable number of additional satellites to provide adequate coverage for precision approaches.[9] Reliance on the U.S.S.R. GLONASS constellation is fraught with political and technical risks.

- Accuracy. While near CAT I requirements may be achieved with differential enhancements, current GPS vertical accuracy is not sufficient to support CAT II or III operations.

- Integrity. GPS cannot currently provide adequate warning time of incorrect guidance. Techniques for providing this capability are being developed.

In terms of the requirements for the terminal area in the year 2000, the capabilities of a satellite-based system to provide adequate guidance to support precision approaches has not been determined. If the capability to perform near CAT I approaches using satellite navigation is approved, GNSS would meet three of the four requirements. GNSS would permit advanced procedures throughout an unlimited coverage volume, and could provide service at any runway. However, necessary ground enhancements could restrict operations (e.g., use of pseudolites). Studies to date indicate that GNSS, even with ground enhancements, cannot provide CAT II or III service.[10]

Synthetic/Enhanced Vision Systems

SVS is intended to provide a real time image of the runway environment to the pilot. Ultimately, the image should have sufficient information and resolution to enable the pilot to manually land the aircraft "visually" in zero, or near zero visibility. In the interim, SVS could be used as a supplement to precision approach systems. Technologies currently being evaluated to provide this operational capability include passive infrared and active millimeter wave radar.

The proposed SVS would provide an image of the runway when the aircraft is within 1 to 3 NM of touchdown. It does not provide guidance to support the initial portion of the approach-- this would have to be provided by some other navigation system.

It has been proposed that SVS may permit CAT II/III type approaches to be conducted using CAT I facilities (assuming necessary obstruction clearances can be met). However, the system capable of conducting such procedures has yet to be developed. If achieved, implementation would be a major departure from current, internationally accepted, autoland technology. A system with this capability is unlikely to be available by the year 2000.

COSTS AND SCHEDULES

ILS is a proven technology, and is available at over 800 locations in the U.S. It is estimated that between 10 and 20 percent of the air carrier fleet is also equipped with RNAV. The other aircraft must acquire RNAV capability to achieve the benefits of RNAV/ILS. Due to FM interference problems, existing ILS receivers must be modified or replaced before 1998, representing an additional cost. Appropriate RNAV system costs and the high cost of retrofit may limit applications to new, large air carrier aircraft only.

MLS is available now and has already undergone lengthy international coordination, planning, and development. Several countries are proceeding with MLS procurement programs, and in the United States, CAT I MLSs have been deployed at several locations. However, CAT II/III systems will not be available until 1994. Current cost estimates[11] for MLS avionics, including installation, range from $6,000 for a general aviation aircraft to $180,000 for a modern air carrier type aircraft. MLS Demonstration Program User Benefit Analysis results estimate that the payback period for investment in MLS is six years.[12]

User costs for GNSS vary widely depending on who pays for the satellite service. Depending on the configuration and the type of enhancements, GNSS is estimated to cost each air carrier user up to a total of $600,000 for a 20-year period. By comparison, MLS is estimated to cost each user up to $130,000 for the same operating period.[13] With the number of technical and political challenges facing GNSS, it is unlikely that it could be used for precision approaches until the next century.

SVS has been described by some airlines as a practical approach to precision landings, and by others as a "leap in the dark."[14] It is still at an early development stage, and is a new concept for precision landings in civil aviation. Initial cost estimates for the development and implementation of SVS are between $250,000 and $400,000 per aircraft (excluding certification costs).[15] The high cost would likely limit applications to new, large air carrier aircraft only.

CONCLUSIONS

Four key capabilities are required for precision approach systems in the year 2000:

- Precise position information to enable computed guidance for advanced operations.

- Wide area coverage to facilitate efficient transition between phases of flight.

- Capability to provide service at all required locations.

- Operation unaffected by weather.

These requirements can be applied to four candidate precision approach systems-- RNAV/ILS, MLS, GNSS, and SVS-- as follows:

- RNAV/ILS will partially meet the requirement for precise position information by allowing performance of curved approaches at a limited number of locations. It fully satisfies the requirement for wide area coverage, but does not have the capability to provide service at all required locations due to ILS siting limitations and the very large protected airspace associated with the non-precision RNAV portion of the approach. ILS can provide precision landing capability down to CAT III minima.

- MLS satisfies all of the operational requirements identified. It provides full capability for advanced procedures, at any required location. MLS provides ±60 degrees coverage, and precision guidance to CAT III minimums.

- GNSS can potentially satisfy three of the four identified requirements. The system would permit the full range of advanced procedures at any location, and provide a wide coverage area-- dependent on the availability of ground enhancements. However, GNSS currently does not meet accuracy requirements below CAT I minimums.

- SVS is still in the conceptual stage. It has a potential role to provide supplemental visual guidance on the final portion of a precision approach. As such, it is not a viable alternative precision approach system for the year 2000.

All four alternatives require additional user investment. The newer technologies will incur more development costs. RNAV/ILS will have the least amount of development costs, SVS the highest. MLS has been developed and deployed to CAT I;

additional development costs will not be as extensive as those for GNSS or SVS.

All four alternatives also carry some technical risk. RNAV/ILS has the least amount of risk, but the issue exists as to how extensive is the application of RNAV capabilities, and channel capacity will limit the number of sites. MLS carries relatively little risk, as the system is in service in some locations. However, CAT II/III MLS systems are not yet available, nor are the avionics to perform advanced procedures. GNSS offers significant technical risk. No standards exist for satellite use for precision approach, and it has not yet been determined if GNSS can safely perform this function. Integrity and continuity of service issues are yet to be resolved in addition, significant political and institutional issues exist concerning the use of the USSR GLONASS satellites. A prototype SVS has yet to be developed or tested.

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