



CHINA CIVIL AVIATION

# Performance-Based Navigation Implementation Roadmap



**中国民用航空局**  
Civil Aviation Administration of China



## PREFACE

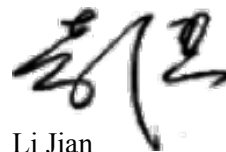
# The China PBN Roadmap

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Performance-based navigation (PBN) is a new operational concept presented by the International Civil Aviation Organization (ICAO) on the basis of integrating the operational practices and technical standards of area navigation (RNAV) and required navigation performance (RNP) in various parts of the world. PBN, combining advanced onboard equipment with satellite-based navigation and other state-of-the-art technologies, covers all phases of flight from en route and terminal area to approach and landing, and enables a safer and more accurate flight model and a more efficient air traffic management (ATM) model.

A key transformation of flight operations, PBN can effectively promote continuous civil aviation safety, increase airspace capacity, reduce ground navaid investment, lower energy consumption and emissions, etc. It serves as one of the core technologies for China to shift from a nation large in aviation quantity to a global aviation leader and to develop China's next-generation air transportation system. The Civil Aviation Administration of China (CAAC) resolves to expedite the applications of PBN and organize all-round implementations in accordance with the requirements of the ICAO and Asia/Pacific PBN Implementation Planning.

Based on the actual situations in China, this Roadmap specifies the policies and overall work plan of the CAAC on PBN implementation up to 2025, provides guidance to the stakeholders and facilitates worldwide harmonization of aviation standards and international cooperation. The CAAC encourages comments from all participants in the nation's air transportation system to update and improve the Roadmap during implementation in order to keep pace with the actual requirements of rapidly developing civil aviation in China and serve as a milestone plan on developing new navigation technologies in China and an exemplary blueprint of the international aviation community.



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## SECTION 1

# Background

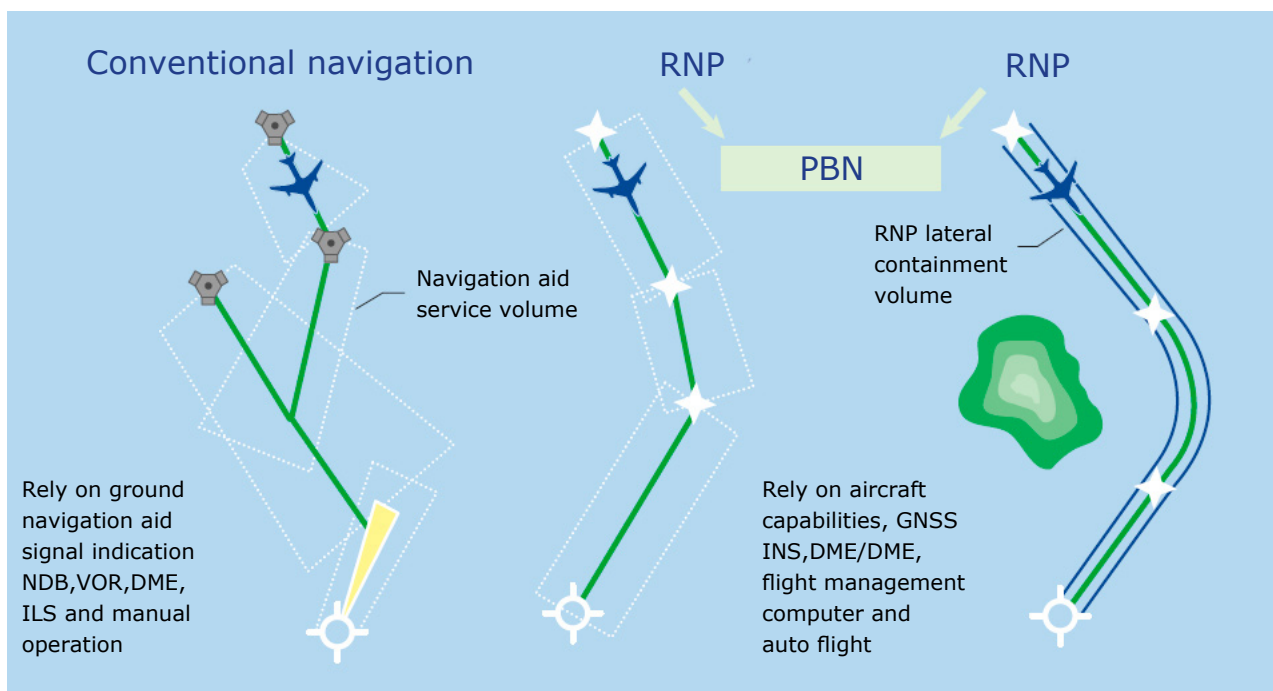
## 1.1 The PBN concept

In conventional air navigation, the aircraft is guided to fly inbound or outbound by receiving signals from ground-based navigation aids, and the route design and flight procedures in the terminal area are restricted by the placement of ground-based navigation infrastructure and type of navigation aids. With improving onboard equipment capabilities and the ongoing evolution of satellite-based navigation and other state-of-the-art technologies, the ICAO has presented the concept of performance-based navigation (PBN).

PBN refers to the aircraft's performance requirements in terms of system accuracy, integrity, availability, continuity, and functionality for operations along a given route, within an instrument flight procedure or a particular airspace, and with the availability of pertinent navigation infrastructure. The introduction of the PBN concept represents a shift from sensor-based navigation to performance-based navigation.

PBN operations combine three fundamental elements: the navigation application, the navigation specification, and the navaid infrastructure supporting system operations. A navigation specification is a series of requirements placed on the aircraft and flight crew within a defined airspace. It defines the performance and specific functional requirements of PBN implementation, and identifies how to select navigation sources and facilities. PBN includes two basic navigation specifications: area navigation (RNAV) and required navigation performance (RNP).

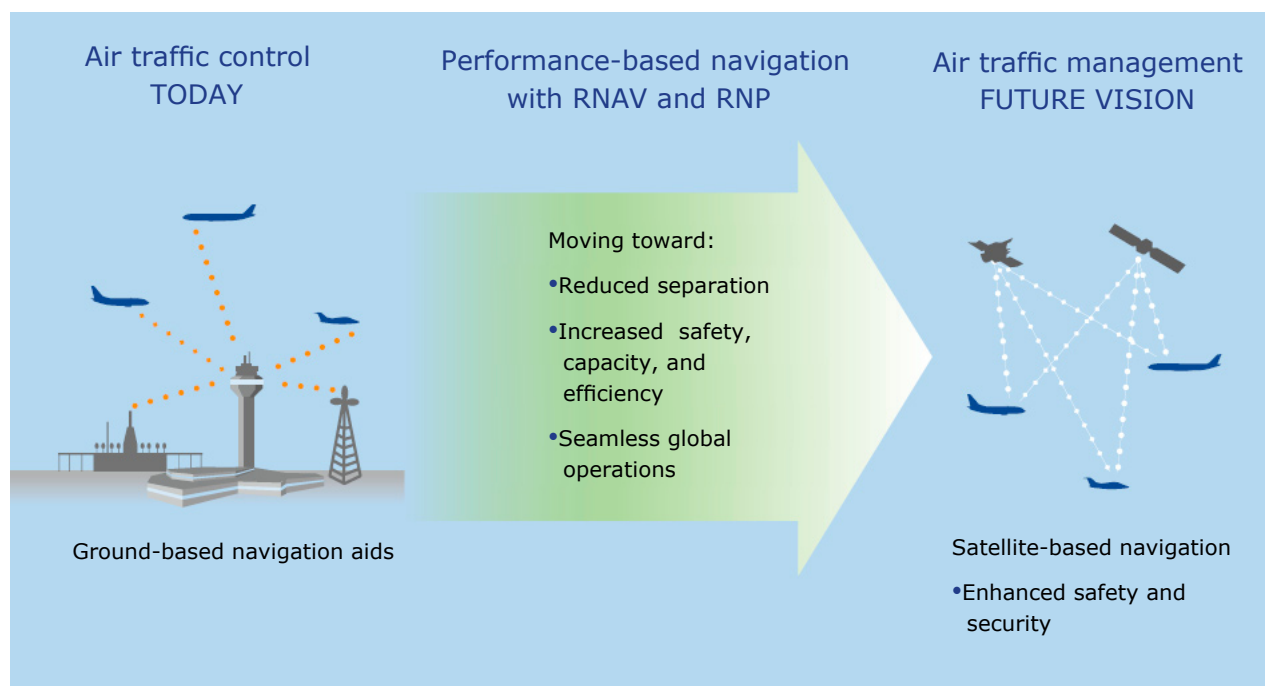
Figure 1-1: The PBN concept



## 1.2 Effect and benefits of PBN

- To improve the safety of flight operations by accurately guiding aircraft.
- To provide vertical guidance and implement continuous steady descent procedures to reduce the risk of controlled flight into terrain (CFIT).
- To improve all-weather operations and flight schedule reliability, and ensure safe operations at airports surrounded by complex terrain.
- To achieve optimized flexible flight paths, increased aircraft payloads, reduced flight times, and reduced fuel consumption.
- To be environmentally progressive by reducing aircraft emissions and avoiding noise-sensitive areas.
- To increase traffic flows by means of parallel routes and additional fixes along the arrival and departure flight paths within terminal areas.
- To increase airspace capacity by reducing the lateral and longitudinal separation between aircraft;
- To alleviate controller and pilot workload by facilitating ATM instructions and reducing the need for ground-to-air voice communications and radar vectoring.
- To improve the overall economic benefits of operations by reducing navigation infrastructure investment and operational costs.

Figure 1-2: Transition from conventional navigation to PBN





## 1.3 ICAO requirements

At the 36th Session of ICAO Assembly, it was resolved that: “All the contracting States should have a PBN implementation plan in place by 2009 to ensure a globally harmonized and coordinated transition to PBN by 2016.” The specific requirements are as follows:

- Each contracting State should develop an implementation roadmap and implement RNAV and RNP operations from the en route to terminal areas according to the established schedule;
- Each contracting State should implement approach procedures with vertical guidance (APV) employing baro-VNAV and/or augmented global navigation satellite system (GNSS) for all instrument runway ends, either as the primary approach or as a back-up for precision approaches, by 2016, and meet the intermediate implementation milestones of 30% by 2010 and 70% by 2014.

## SECTION 2

# Purpose of the China PBN Roadmap

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ICAO has reached a consensus with the contracting States and other international organizations that PBN represents the main trend of future global navigation technology. China provides this PBN Roadmap to ensure consistency between RNAV and RNP operations in China and the concept of PBN; provide guidance on PBN implementation for the regulatory authorities, air operators, air navigation service providers, and airports; provide planning for future air navigation development for the entire industry; and assist the stakeholders in formulating their transition plans and investment strategies.

## 2.1 To document plans and decisions

In the Roadmap, the CAAC specifies PBN implementation decisions and planning; presents the overall strategic objectives and timeframe; specifies the operational requirements for PBN implementation in China; describes the PBN navigation specifications for en route and terminal areas; analyzes existing Chinese fleet capabilities to support PBN implementation; presents fleet modification planning; defines PBN operational requirements upon the CNS/ATM system; avoids improper development of ground-based infrastructures and repeated modifications of on-board equipment; and addresses integration PBN with other pertinent technologies.

## 2.2 To aid communication and understanding

Each State's PBN roadmap is an important visibility and coordination tool for promoting open communication about and broader understanding of that State's PBN implementation, serves to provide greater visibility, avoids iterant airworthiness and operational approvals, and achieves global PBN coordination and harmonization.

The PBN roadmap provides specific guidance to the State's air navigation service provider and its airspace users. It identifies for all participants the steps and phases required for implementing PBN operations within the planned environment, infrastructure, and time frame so as to realize operational benefits while satisfying the operational and performance requirements.

## 2.3 To define responsibilities

PBN implementation will profoundly transform all parts of China's air transportation system. The Roadmap specifies each participant's role and requirements, explains potential benefits, and helps analyze and identify the difficulties and challenges inherent in implementing PBN so as to support vital national strategic decisions and investment. The CAAC will include in its annual PBN plan a description of implementation details.

## SECTION 3

# China's civil aviation transportation system

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## 3.1 Current status

The civil aviation industry of the People's Republic of China has made remarkable achievements over six decades, and has greatly contributed to the national economic and social development. The average annual growth of civil air traffic was as much as 17.5% between 1978 and 2008. China ranks second worldwide in the total volume of air transportation. In 2008, the volume of air transportation totaled 37.4 billion tonne-km, including 194 million total enplanements and up to 4.03 million tonnes of cargo and mail. Scheduled domestic flight operations today embrace about 160 airports and 1,532 flight routes. Internationally, 16 Chinese airlines perform scheduled flight operations on routes to 108 cities in 47 countries and regions worldwide.

Working to the guiding principle of “safety first with a focus on prevention and comprehensive control,” the CAAC has constantly improved its safety regulations and supervision system, implemented safety responsibility and accountability at every level, and achieved remarkable results over the decades. By April 2009, China had amassed the best aviation safety record in its history with over 15 million safe flight-hours.

Since the start of this new century, and through its “Eleventh Five-Year Plan,” China has substantially improved its civil aviation infrastructure with better assurance capabilities; has focused on constructing, renovating, and expanding more than 80 medium-sized and large airports; and has built a group of regional airports that significantly enhance air transportation accessibility. Civil aviation services have also been improved through a series of regulations aimed at protecting the interests of consumers, launching quality services, and ensuring flight punctuality.

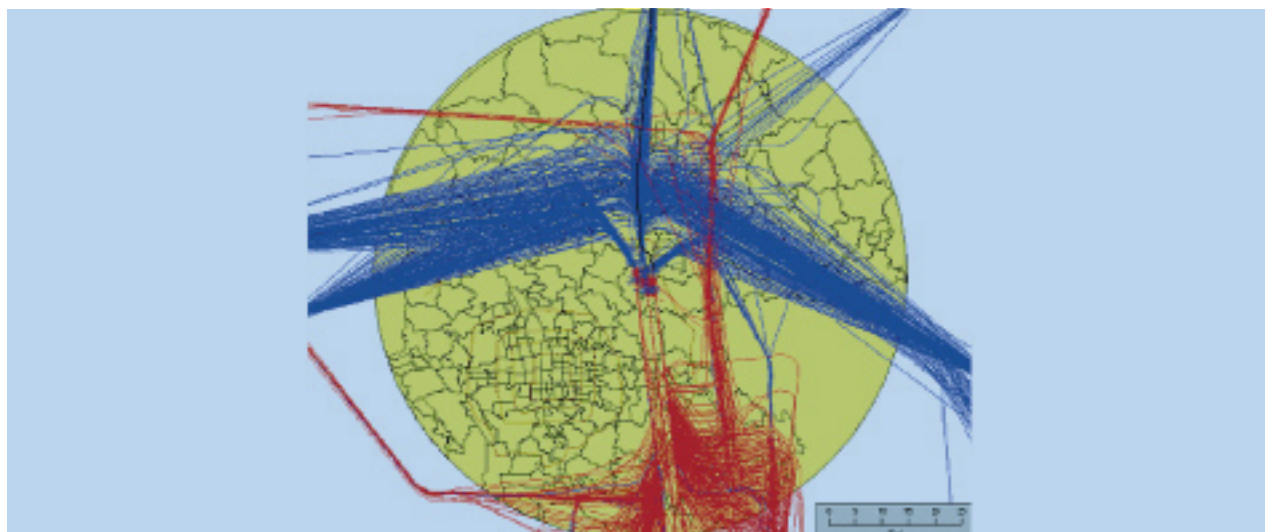
## 3.2 Challenges

China's air transportation system is safe and capable, but it faces a number of challenges from rapid development. These mainly include:

### Constrained airspace and airports

Rapid growth in traffic levels leads to air traffic congestion. Due to limited ground resources and restricted airspace, some airports operate nearly at full capacity. For example, Beijing/Capital International Airport has nearly 1,400 landings and takeoffs daily. Moreover, increasing use of various types of aircraft will further congest the limited airspace, and the existing operational concept and technologies cannot fully satisfy the requirements of this traffic growth.

Figure 3-1: Beijing Capital Airport 24-hour arrival (red) and departure (blue) tracks



### Many special airports

Special airports are those airports located in areas with complex flight environments and insufficient airport infrastructure. They thus need special measures to ensure flight safety. China has now 39 special airports, including 9 airports at high elevations over 2,438 meters (8,000 feet). More high elevation and complex airports are under construction. In such airports and areas, the influence of terrain and geographical conditions makes it difficult to satisfy the operational requirements through conventional ground-based navigation aids, which require significant investment and high maintenance costs.

Figure 3-2: Linzhi Airport in Tibet with the most complex terrain in China



### Insufficient coordination of aviation development

Constraints on available airspace, human resources, infrastructure, etc., exist in China, and current operations are highly dependent on the ground infrastructure. China lags behind in regional aviation and general aviation, and it also needs to further improve the overall level of operational safety and efficiency.

### Development imbalance between Eastern and Western Regions

China's Eastern Region has a better navigation infrastructure in place with overlapping radar coverage. However, the airspace in this region is congested as a result of heavy civil traffic flows. This congestion may worsen in the future, requiring more efficient use of airspace resources. The Western Region has an incomplete infrastructure with insufficient navigation and radar coverage. Therefore, the civil aviation infrastructure will contend with severe challenges as a result of rapid economic development in the Western Region.

## 3.3 Future development

In accordance with the national aeronautics and space development strategy, China has launched the civil "large aircraft" program and the next-generation Compass satellite navigation system, indicating that China's civil aviation transportation system may hopefully become independent in R&D and system operation. Development of the national economy will make it necessary to gradually open up more airspace, enhance efforts to support general aviation, and drive sustainable rapid growth of the aviation industry in China.

China's civil air transportation system is predicted to grow 10% annually on average over the next 10 years, and by 2020 the total turnover will likely exceed 140 billion ton-km, with enplanements of over 700 million passengers, accounting for more than 25% of the total passenger turnover for all transportation modes nationwide. The airlines' networks will continue to expand. It is expected that there will be more than 240 airports with scheduled commercial service. General aviation airports are also increasing.

## SECTION 4

# PBN implementations

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## 4.1 Overall objectives

- Improve aviation operational safety.
- Improve operational benefits.
- Lower operational costs.
- Achieve harmonization with global standards.

## 4.2 Key tasks

The key tasks necessary to realize the above objectives include:

- Develop a regulation and standard system consistent with global standards.
- Gradually apply PBN navigation specifications for route planning and operations.
- Implement RNAV or RNP standard instrument departures (SID) and standard terminal arrival routes (STAR) procedures in the terminal areas.
- Implement RNP approaches, including RNP AR approaches for airports in need, and to gradually implement GLS approaches.
- Use WGS84 coordinates, and ensure accurate, integral, and punctual aviation data.
- Upgrade the communication, navigation, and surveillance (CNS) facilities and equipment and enable coordinated development with other new navigation technologies.
- Develop PBN quality assurance systems and conduct safety assessments in accordance with ICAO requirements.

### 4.2.1 Formulation of regulations and standards

PBN regulations and standards encompass onboard equipment standards, aircraft airworthiness qualifications, training of personnel (flight, maintenance, dispatch and air traffic control), operation procedures, certification and approval, monitoring and inspection, CNS/ATM, flight procedure design criteria, etc. The CAAC will establish a complete regulation system conforming to ICAO PBN standards by the end of 2010.

### 4.2.2 Route planning and flight procedure design

The CAAC will by 2010 establish PBN flight procedure design capability and route planning capability, design PBN flight procedures for air operators and airports, provide flight procedure demonstration and quality control, and provide on-the-job training of flight procedure design and review personnel. All qualified and approved operators can use these new routes and procedures.

### 4.2.3 Establish operator capability

To implement PBN operations, the air operators must ensure that their aircraft are properly equipped to meet the requirements as specified in the applicable PBN navigation specification, establish operational procedures, complete the training of personnel as specified, and apply for and obtain CAAC operational approval.

The air operators shall, in accordance with CAAC PBN implementation planning and operational need, gradually establish operational capabilities and obtain their PBN operational approvals.

### 4.2.4 Promote education and training

The CAAC will, during PBN implementation, provide training for and disseminate educational information about its PBN implementation program. Training shall be provided to personnel from the regulatory authorities, air traffic management agencies, airports, air carriers, etc., by the PBN training centers and organizations authorized by the CAAC. Training materials will be regularly updated to ensure that trainees are punctually informed of the latest progress and technical information about PBN. The universities shall incorporate PBN theory into their curricula, offer courses related to PBN technologies, and include PBN as a subject in flight training.

### 4.2.5 International harmonization

Because China's civil air transportation system is a key component of global air transportation, the CAAC needs extensive international coordination for PBN implementation. This mainly includes:

- Coordination with the regulatory authorities of other countries/territories to avoid iterant airworthiness and operational approvals among countries/territories.
- Communication with foreign operators and aviation associations to inform them of PBN implementation progress and requirements in China.
- Timely tracking of implementation progress and requirements abroad to ensure that Chinese operators ready for PBN operations.
- Coordination to enable effective route linking with surrounding countries and territories.
- Coordination with aircraft manufacturers to understand the evolution of aircraft performance and represent China's on-board equipment configuration requirements.
- Advising ICAO on China's PBN implementation progress and representing China's opinions and recommendations to the global community.
- Providing help and guidance on PBN implementation to related countries and territories as requested.

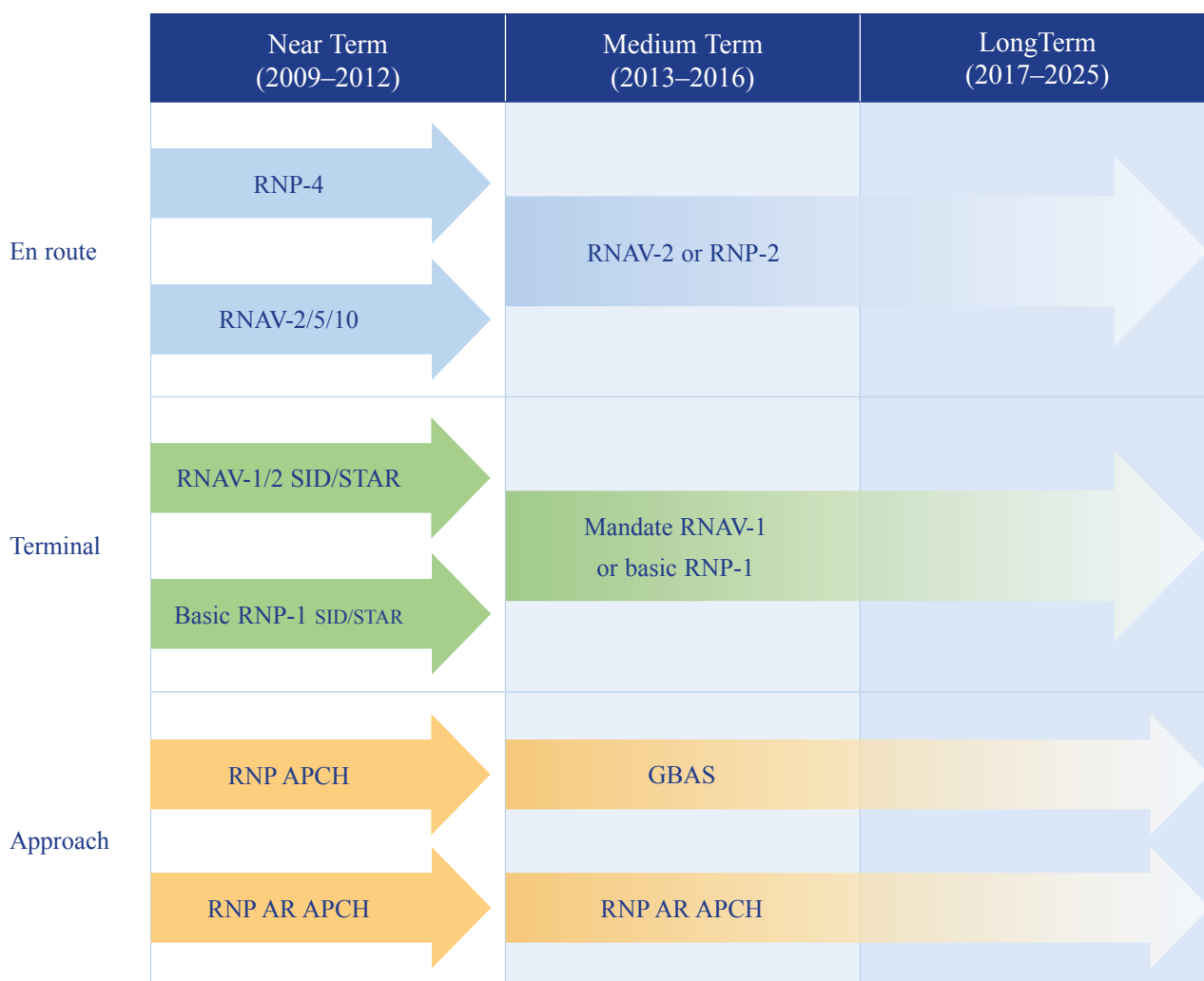


## SECTION 5

# Implementation time frames

The CAAC will implement PBN in three phases: near term (2009–2012), medium term (2013–2016), and long term (2017–2025). The near-term phase focuses on selected applications of PBN, the medium-term phase focuses on overall application of PBN, and the long-term phase targets integration of PBN with communication, navigation, and surveillance/air traffic management (CNS/ATM), the foundation for China’s “next generation air transportation system.”

Figure 5-1: China PBN implementation phases





## 5.1 Near term (2009-2012)

### En route

Based on air transportation requirements, surveillance and communication capability, controller workload, and fleet equipage, the CAAC plans to selectively apply RNP-10 and RNP-4 navigation specifications to certain oceanic operations and continental operations in western China. For certain busy routes, RNAV-2 or RNAV-5 navigation specifications are selectively applied, based on coverage of communication and surveillance signals, for reduced route spacing and higher utilization of airspace. Existing RNAV/RNP routes will be readjusted in accordance with PBN navigation specifications.

### Terminal area

The CAAC plans to apply RNAV-1 navigation specifications to terminal-area operations in China where radar, GNSS, and ground-based navigation infrastructure are available. RNAV-1 implementation shall start at international airports and busy airports where coexistence of PBN operations and conventional operations is allowed. RNAV operations shall be implemented at 30% of airport terminal areas nationwide and all the nation's international airports by 2012. In the airport terminal areas where there is partial radar coverage or insufficient ground-based navigation aids, the CAAC will selectively use GNSS navigation to implement basic RNP-1 SID and STAR procedures.

### Approach

The CAAC plans to implement GNSS-based RNP APCH procedures, supported with APV based on Baro-VNAV, at all newly built airports and some existing airports. These APV approach procedures will serve as the primary approach or as a backup for ILS precision approaches. RNP AR approach procedures will be used at certain airports where there is complex terrain and limited airspace depending on operational requirements. RNP approach capability will be available to 30% of instrument runway ends nationwide by 2012. RNP APCH or RNP AR approach procedures will be mandated in certain airports. In this time frame, conventional navigation aids and flight procedures will be retained for aircraft without PBN capabilities.

Table 5-1: Selection of near-term navigation specifications

Near Term (2009-2012)		
Airspace	Recommended Navigation Specifications	Acceptable Navigation Specifications
Route - oceanic	RNP-4	RNAV-10
Route - remote continental	RNP-4	RNAV-10
Route - continental	RNAV-2, RNAV-5	
Terminal area - arrivals and departures	RNAV-1 (radar coverage and sufficient navigation aids) Basic RNP-1 (no radar coverage)	
Approach	RNP APCH (with Baro-VNAV) at some airports RNP AR APCH to be implemented at airports with operational requirements	RNP APCH

## 5.2 Medium term (2013-2016)

### En route

The CAAC plans to implement RNP-4 navigation specifications on oceanic and western routes for reduced lateral and vertical separation (e.g., 30NM×30NM, based on automatic dependent surveillance–contract (ADS-C) and controller pilot data link communication (CPDLC). With the establishment of route spacing standards for RNAV-2 and RNP-2, more and more RNAV/RNP routes will be added to the busy eastern continental airspace, and parallel RNAV/RNP routes will be opened. RNAV-2 navigation specifications will continue to be applied on routes with sufficient GNSS or DME/DME coverage. RNP-2 navigation specifications will be applied to certain busy routes and routes without radar coverage.

### Terminal area

The CAAC plans to implement RNAV-1 and RNP-1 for all airport terminal-area operations within China by 2016 and, depending on operational requirements, to mandate the application of RNAV-1 or RNP-1 at certain airports. Where PBN operations co-exist with conventional operations, the CAAC plans to grant preferred route access to aircraft with PBN capability.

### Approach

The CAAC plans to expand implementation of RNP APCH with Baro-VNAV in approach operations. By 2016, RNP approach capability will be available to all instrument runway ends. RNP AR approach procedures will be implemented at airports with operational requirements. The CAAC plans to introduce landing operations based on GNSS and GBAS (i.e., GLS) for transitions to high-performance approach and landing capability.

Table 5-2: Selection of medium-term navigation specifications

Medium Term (2013-2016)*		
Airspace	Recommended Navigation Specifications	Acceptable Navigation Specifications
Route - oceanic	RNP-2*, RNP-4	RNAV-10
Route - remote continental	RNP-2*	RNAV-2, RNP-4, RNAV-10
Route - continental	RNP-2*	RNAV-2, RNAV-5
Terminal area - arrivals and departures	RNAV-1 or RNP-1	
Approach	RNP APCH (with Baro-VNAV) RNP AR APCH at airports with operational benefits Introduced landing operations using GNSS and its augmentation systems	
*The CNS requirements and operational procedures related to RNP-2 application are to be defined		

### 5.3 Long term (2017-2025)

PBN operations will be primary in all phases of flight, including en route, terminal area, approaches, etc., and co-existence of conventional operations and PBN operations will evolve into full PBN operations within this time frame. The CAAC plans to employ performance-based traffic segregation and performance-based preferred routings in en route operations. The overall route structure will be replanned with PBN technology, and all conventional routes will be transitioned to PBN routes. PBN operations will be systematically implemented in the terminal area. It is expected that GNSS and its augmentation systems will support precision approach capability. Depending on operational value and commercial benefits, the CAAC plans to widely implement GLS approaches.

PBN operations will be heavily based on GNSS. The CAAC will use GNSS based on multilateral cooperation, including consideration of using the Compass satellite-based navigation system. PBN will be integrated with other advanced assurance systems. For example, it can be combined with automatic dependent surveillance–broadcast (ADS-B) surveillance technology and satellite-based data link communications systems for augmented operational capabilities and coordinated development with CNS/ATM.

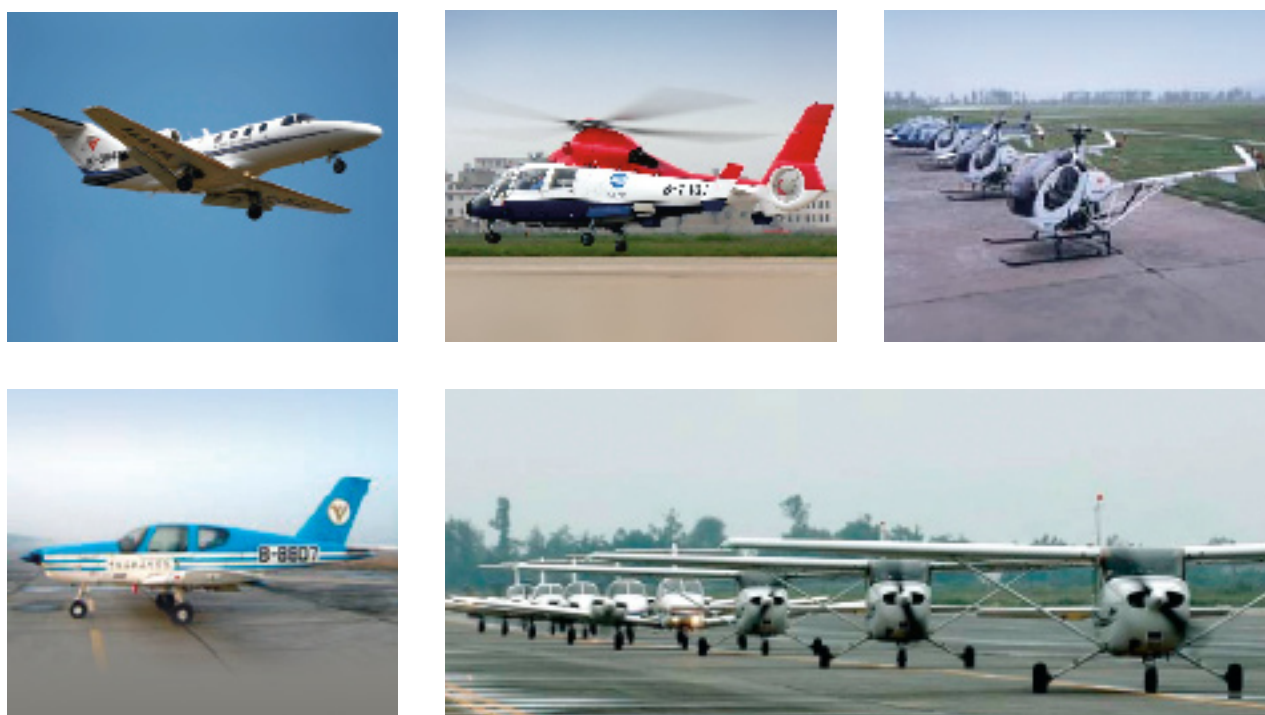
## SECTION 6

# General aviation

## 6.1 Current status

General aviation refers to all civil aviation operations other than public air transport with civil aircraft, including aerial work in the fields of industry, agriculture, forestry, the fishery and construction industries, flight operations in the fields of medical and health work, emergency and disaster relief, meteorological services, ocean monitoring, scientific experimentation, education, training, culture, and sports.

Figure 6-1: Examples of general aviation aircraft models in China



General aviation is growing rapidly in China. In 2008, general aviation flight hours reached 122,700, up 7.5% compared with 2007.

At the end of 2007, the nation's general aviation fleet consisted of 801 aircraft, and 74 businesses were engaged in general aviation operations.

China's general aviation activities fall mainly into these four categories:

- Foundational services for the development of civil aviation.
- Social and public services.
- National economic development services.
- Aviation consumer market services.

Among the above categories, examples of specific services include ocean platform support, forest fire protection, petroleum pipe services, power line patrolling, etc.

## 6.2 Development strategy

Growth in the general aviation sector increases the need for China to build its civil aviation system scientifically and comprehensively. China attaches importance to and supports the development of general aviation. It is estimated that China's general aviation sector will experience rapid growth in the coming years.

Because the nation's diverse general aviation fleet operates flexibly in various fields and for various purposes, its need for CNS services is remarkably varied. The CAAC supports and encourages general aviation operators to gradually implement PBN and establish RNAV and RNP capabilities to further improve flight safety and reap beneficial economic and environmental operating efficiencies.

The CAAC plans to require general aviation aircraft to be equipped with GNSS navigation systems allowing them to perform PBN. GNSS systems compatible with multiple-constellation satellite-based navigation systems, including Compass, will be the preferred navigation system for the general aviation sector in the future.

SECTION 7

Aircraft capabilities

The introduction of PBN navigation specifications to China’s civil aviation will require changes to how some aircraft are equipped. These equipage changes are an important part of the broader evolution of CNS technologies in China.

Aircraft equipage changes shall be based on the needs of the actual situation, scientific decision-making, overall planning, and step-by-step implementation. These equipage changes will keep pace with the latest developments and changes of internationally advanced technologies. They will be compatible with internationally advanced standards, and will be oriented by practical effects.

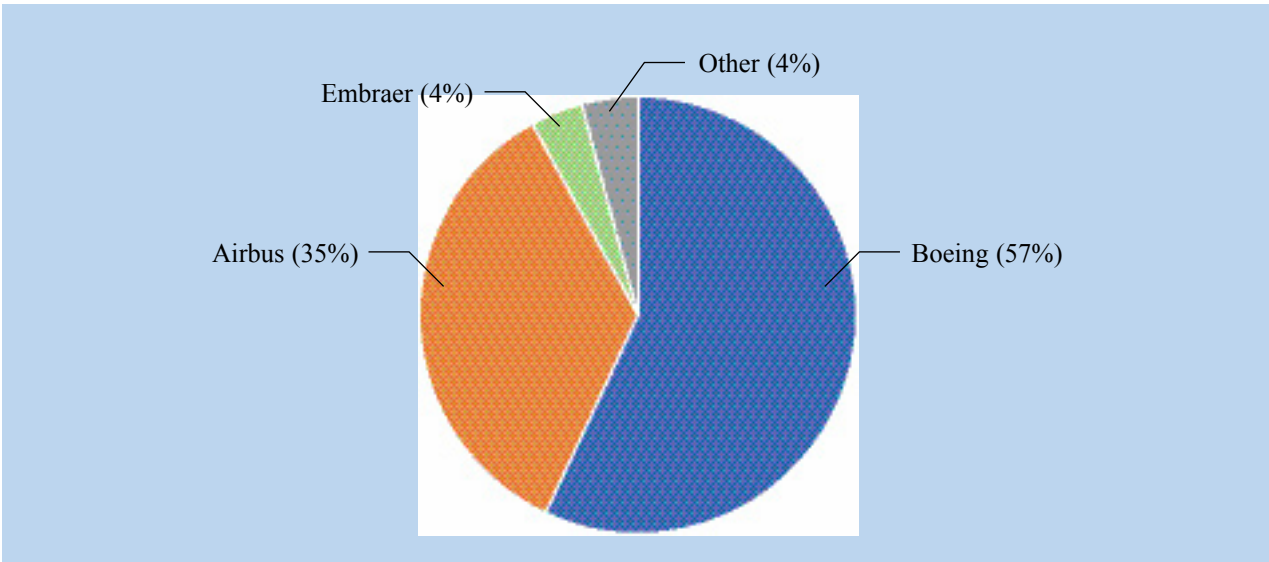
This PBN Roadmap addresses onboard navigation equipment modification only. When operators introduce new airplanes or retrofit airplanes already in service, they should comply with the technical standards of the CAAC and ICAO, with consideration to the overall CNS requirements. These plans might not be limited to navigation equipage modification alone.

Foreign air operators operating in China shall be equipped as per PBN navigation specifications.

7.1 Overall status of existing fleet

The statistics as of June 2009 show that the Chinese fleet consists of 1,332 registered transport aircraft, including 767 Boeing aircraft, 462 Airbus aircraft, 50 Embraer aircraft, 20 Bombardier aircraft, 29 Dornier aircraft, 5 ATR aircraft, etc.

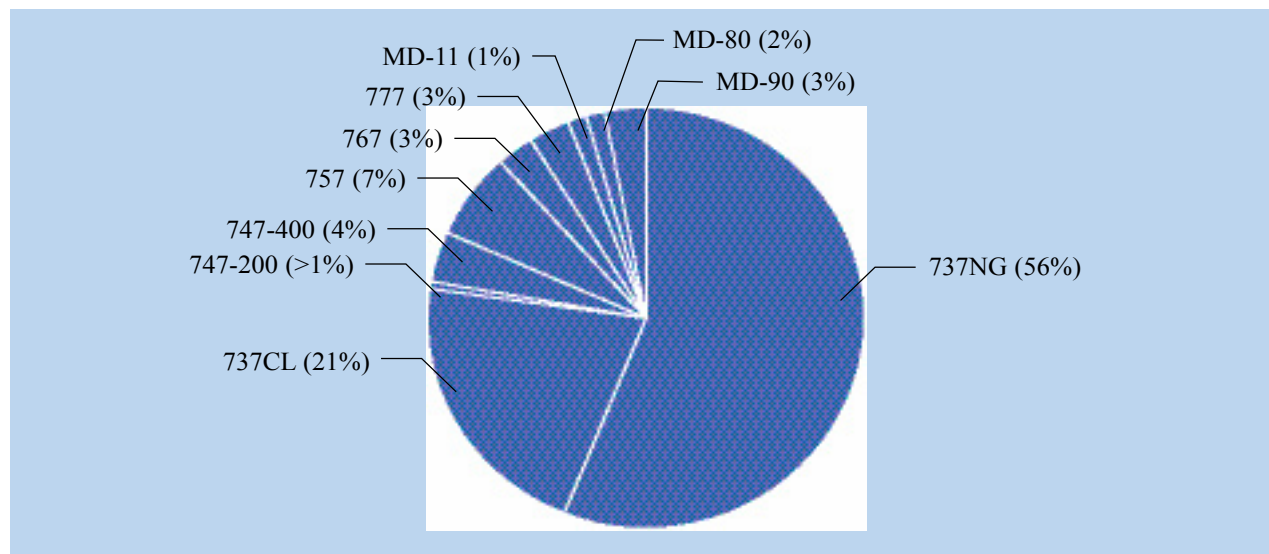
Figure 7-1: Market share by aircraft manufacturer



The breakdown of Boeing and Airbus aircraft models is as follows:

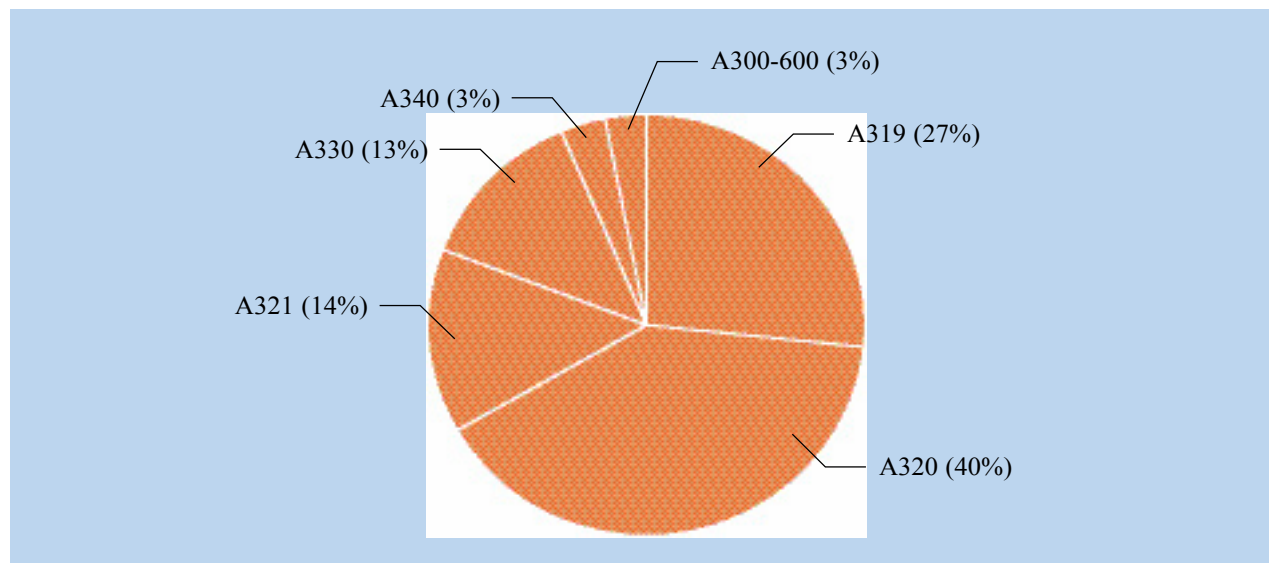
Boeing aircraft									
737NG	737CL	747-200	747-400	757	767	777	MD-11	MD-80	MD-90
431	163	3	30	52	21	23	10	12	22

Figure 7-2: Boeing aircraft by model



Airbus aircraft					
A319	A320	A321	A330	A340	A300-600
124	185	65	59	16	13

Figure 7-3: Airbus aircraft by model



Note: The above data excludes Hong Kong, Macao, and Taiwan.



## 7.2 Onboard equipment standards

ICAO PBN navigation specifications define the required CNS capabilities of aircraft.

Table 7-1: Aircraft CNS capabilities by PBN navigation specification

ICAO PBN Navigation Specification	Primary Navigation Sensor	Ground Navaid Infrastructure	Communication/ Surveillance
RNAV-10 (RNP-10)	GNSS, INS/IRS	N/A	None specified
RNAV-5	GNSS, DME/DME, VOR/DME,INS/IRS	VOR,DME	Voice / radar
RNAV-1/2	GNSS, DME/DME,INS/IRS	DME	Voice / radar
RNP-4	GNSS	N/A	Voice (or CPDLC)/ ADS-C (supporting 30NM×30NM separation)
Basic RNP-1	GNSS	DME	No Comm or Surv specified
RNP Approach	GNSS	VOR, DME, NDB (missed approach)	No Comm or Surv specified
RNP AR ARCH	GNSS	N/A	No Comm or Surv specified

It will be the responsibility of operators to ensure that their aircraft have avionics installed providing the capabilities required to operate in the PBN environment defined by the CAAC.

## 7.3 Available fleet PBN capability

The fleet of commercial aircraft today operated by China-based airlines is well equipped. Most aircraft in this fleet can perform many PBN (RNAV and RNP) operations in accordance with ICAO PBN navigation specifications and CAAC regulations and advisory circulars.

At present, the RNAV and RNP capabilities of China’s in-service transport fleet are as follows:

82% RNAV-1/2 (en route and terminal area).

99% RNAV-5 (en route and terminal area).

78% RNAV-10 (ocean and remote area).

56% RNP-4 (ocean and remote area).

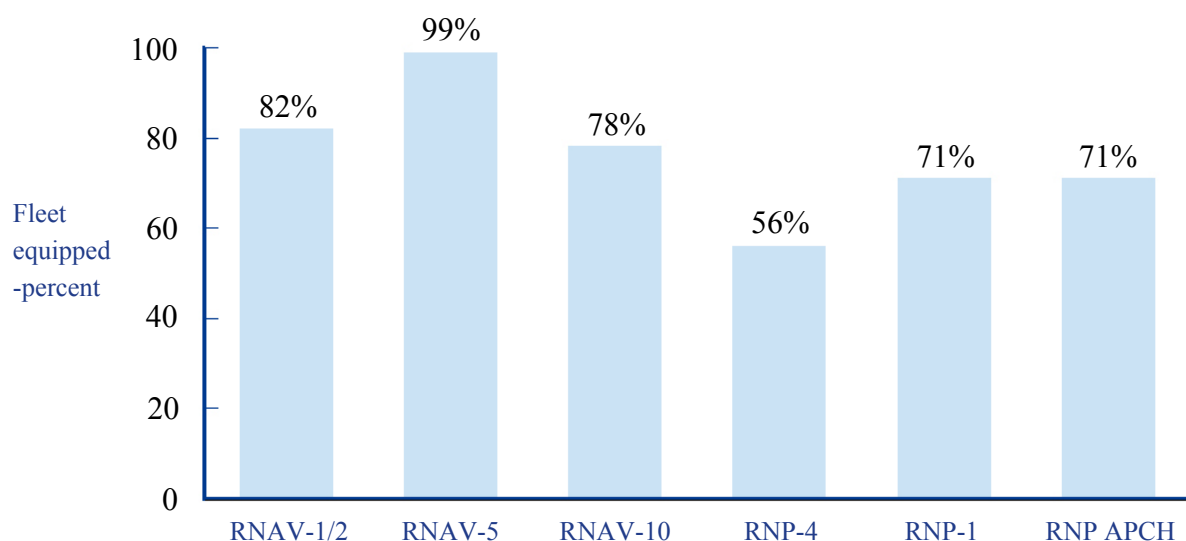
71% RNP-1 (en route and terminal area).

71% RNP APCH approach.



Figure 7-4: Current fleet PBN capabilities

2009



Note that after excluding data for the MD-11, MD-80, MD-90, and 747-200, the percentage of the Boeing fleet that can satisfy RNAV/RNP capability is as follows: 100% RNAV-5, 74% RNAV-1/2, 40% RNP-4 (incorporating CPDLC communication and ADS-C surveillance requirements), 63% RNP-1, 63% RNP APCH, and 63% RNP ARCH.

The RNAV/RNP capability of Airbus models is 100% RNAV (RNAV-1/2/5/10), 92% RNP-4 (incorporating CPDLC communication and ADS-C surveillance requirements), 95% RNP-1, 93% RNP APCH, and after simple modification 61% RNP ARCH.

Based on geographic conditions, economic development, PBN status, etc., in China, the CAAC will establish and implement the PBN capability of China's commercial aircraft fleet in phases according to the overall objectives of the CAAC PBN Roadmap. Specific airports have already begun to exploit RNP AR (RNP 0.3) approaches, mainly using Boeing 737 NG, Airbus A319, and Airbus A330 series aircraft.

## 7.4 Plan for fleet modification

Today the major aircraft manufacturers offer options for delivering all their models ready to operate in all RNAV and RNP environments and provide for upgrading existing aircraft CNS systems. As Chinese operators continue to introduce new aircraft and phase out older models over time, and the CAAC continues to adjust the in-service fleet mix and aircraft configurations, the nation's fleet will continue to improve its PBN capabilities over the coming years.

Air operators need to realize that aircraft modification is an important step towards PBN application. The CAAC supports and encourages Chinese air operators to assess the PBN capabilities of their in-service aircraft, and formulate and when appropriate implement aircraft purchase plans and modification programs in accordance with the near-term, medium-term, and long-term tasks and objectives of the CAAC PBN Roadmap. This will ensure them of aircraft capabilities that will satisfy the CAAC PBN Roadmap requirements and the operational requirements of other countries.

During PBN implementation, the CAAC will establish onboard PBN equipment standards for the aircraft and provide support on many fronts to help Chinese air operators achieve the implementation objectives.

## SECTION 8

# Navigation infrastructure

## 8.1 Current status

### 8.1.1 Conventional navigation infrastructure

As defined in ICAO Annex 10, the term “conventional navigation systems” embraces those ground-based radio-navigational aids in use prior to the introduction of GNSS. The conventional ground-based navigation systems deployed by the CAAC mainly include:

- NDB (non-directional beacon).
- VOR (VHF omni-range).
- DME (distance measuring equipment).
- ILS (instrument landing system).

China’s conventional navigation infrastructure is situated primarily in the eastern parts of the country, and the western parts are not fully covered. As of June 2009, China’s civil aviation transportation system had 446 NDB units, 223 VOR units, 337 DME units, and 209 ILS units. The coverage of VOR/DME signals for the airspace at flight altitudes 3,300m and 8,400m is illustrated in Figures 8-1 and 8-2 respectively.

Figure 8-1: VOR/DME signal coverage at flight altitude 3,300m

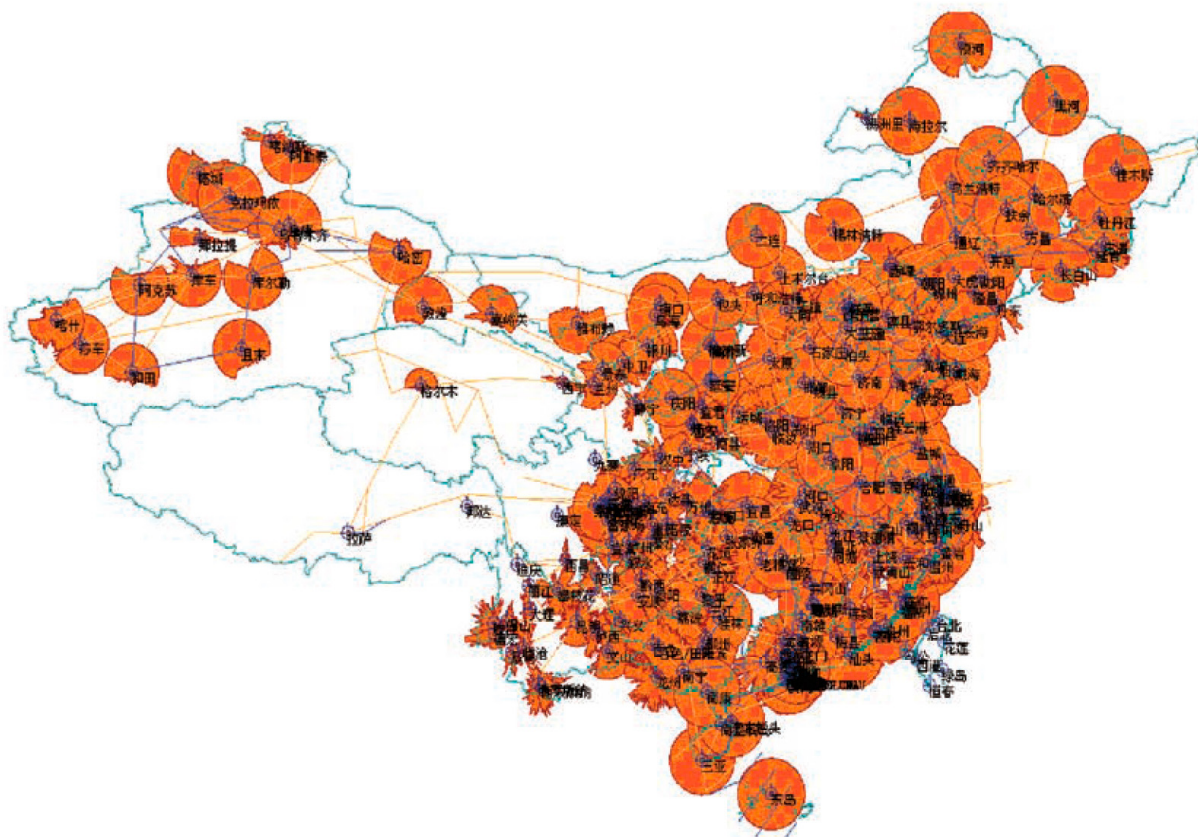
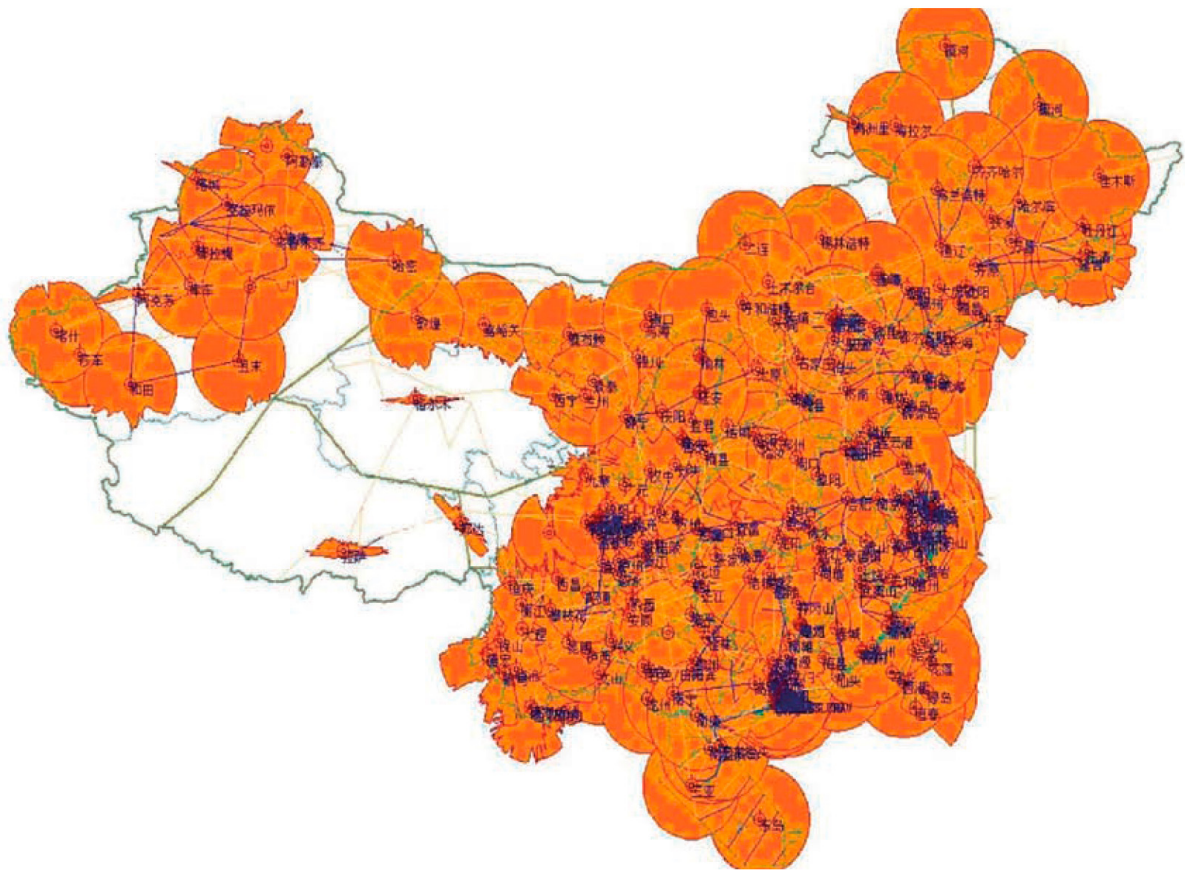


Figure 8-2: VOR/DME signal coverage at flight altitude 8,400m



## 8.1.2 GNSS navigation aids

### 8.1.2.1 Existing GNSS system

GNSS is a system providing position, velocity, and timing (PVT) information and includes one or more satellite constellations. Currently, GNSS consists of two core constellations of GPS and GLONASS as well as their augmentation systems. The GPS constellation is by far the constellation that can best support stable operations in the near and medium term.

ICAO specifies the current and anticipated performance of GPS and GLONASS in Annex 10. For GNSS, formal standards and recommended practices (SARP) were developed and first published in 2000. These SARPs ensure interoperability between components of the GNSS so that equipment based on GNSS operates with consistent performance that meets the operational needs of users within the global aviation community.

### 8.1.2.2 GNSS augmentation systems

Because of GPS and GLONASS performance limitations, additional system components were added to GNSS to augment its performance. These ancillary augmentation systems include aircraft-based augmentation systems (ABAS), satellite-based augmentation systems (SBAS), and ground-based augmentation systems (GBAS).

- Aircraft-based augmentation systems (ABAS)

ABAS systems use GPS information and possibly information from other sensors to perform navigation system integrity monitoring at the aircraft level. Receiver autonomous integrity monitoring (RAIM), a form of ABAS, is by far the most common augmentation in use today. Many other forms of ABAS are possible, such as the integration of barometric altitude auxiliary measurement, or the integration of GNSS and inertial information, to enhance integrity monitoring.

GNSS receivers for aviation use are required to have some ABAS functionality to provide integrity monitoring and alerting when no other augmentation system is available. The most common form of ABAS is fault detection provided by a receiver autonomous integrity monitoring (RAIM) algorithm.

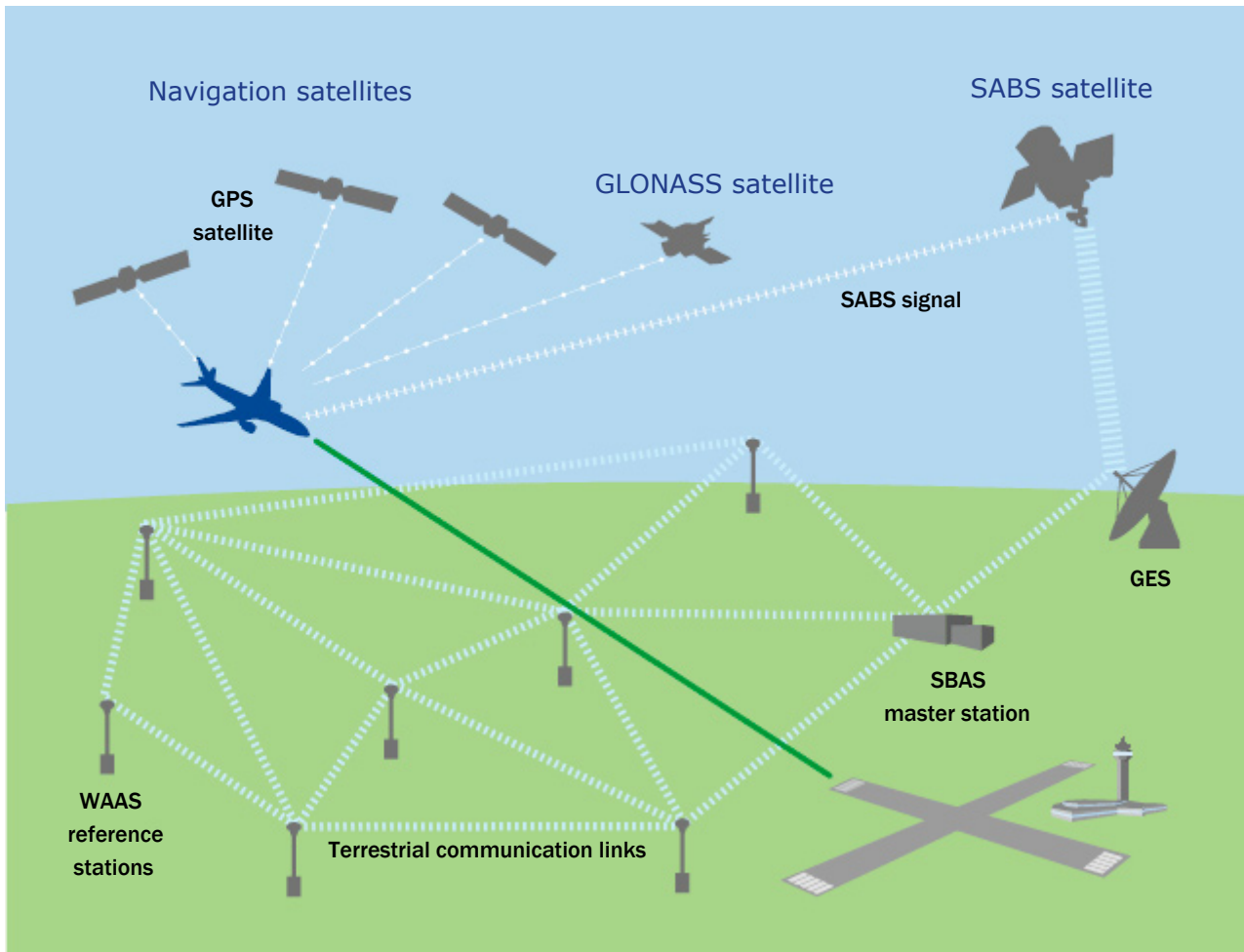
- Ground-based augmentation systems (GBAS)

GBAS is a satellite-based navigation technology consisting of three segments: space system, ground system, and onboard system. The space segment for GBAS comprises the constellations of GPS and GLONASS satellites, as well as ranging sources that may optionally be provided by an SBAS. The GBAS ground system may provide augmentation signals based on GPS alone or, as an option, it may include augmentation information for GLONASS and/or SBAS satellites as well. The GBAS onboard augmentation system normally uses the multi-mode receiver (MMR) and integrates GBAS and ILS receiver functions.

The GBAS ground segment comprises reference receivers and a central processing facility. The central processing facility computes estimates of the pseudorange corrections for each satellite signal observed by the reference receivers, monitors signal integrity and availability and broadcasts such information to the user over VHF data broadcast (VDB). A single GBAS facility can provide services for all the runway ends of the airport at which it is installed.

GBAS can provide effective services for RNAV and RNP operations. The CAAC will rationally use ABAS and GBAS augmentation systems to satisfy the operational requirements of PBN.

Figure 8-3: SBAS system architecture



- Satellite-based augmentation systems (SBAS)

Satellite-based augmentation systems consist of SBAS satellites, onboard SBAS receivers, and ground facilities. These ground facilities are the ground earth station (GES), reference stations, and a master station. A ground communication network links these facilities.

Each reference station includes multiple GNSS receivers that track the satellites in view, measure pseudoranges to the satellites, and transmit those observations to the master station. The master station verifies the integrity of the satellite signals, computes a series of corrections, summarizes other system status data, and broadcasts the processing results to users over a geosynchronous satellite data link. The format of the signals sent by the geosynchronous satellite resembles that of the GNSS satellite signals to facilitate user reception and processing.

In the foreseeable future, SBAS will not be adopted as a GNSS augmentation system for China's civil aviation.



## 8.2 Future GNSS developments

With ongoing evolution, GNSS will incorporate new satellite navigation systems together with additional and better deployed global navigation satellite constellations and R&D of new augmentation systems. At present, in addition to the GNSS system operating and providing services for civil aviation, development is under way of the European Galileo system and China's Compass global satellite navigation system. It is anticipated that in the future operations compatible with multiple satellite navigation systems will be enabled to further enhance the accuracy, continuity, integrity, availability, and functions of the GNSS system in order to satisfy global civil aviation's demands for satellite navigation.

### 8.2.1 Galileo satellite navigation system

The Galileo satellite navigation system is a global satellite navigation system initiated by the European Commission (EC) and European Space Agency (ESA). China is a partner to the Galileo system. Under the system plan, the Galileo constellation will consist of 30 satellites in orbit and associated ground facilities. It is anticipated that lateral navigation precision will be better than 10 meters. The system is now under construction.

### 8.2.2 Modernized GPS

GPS was first developed in 1970s. Although it has performed well, subsequent technological advances have made even greater performance possible. The United States has announced plans to modernize the GPS system by adding additional signals and capabilities to the system. This modernization program includes adding signals for use by the civil community, these being L2c at 1227.60 MHz and L5 at 1176.45 MHz. A new modernized signal, L1c, is planned to be provided at 1575.42 MHz in addition to the L1 C/A signal currently employed by the system. The planned L5 signal is specifically intended to support aviation applications. Introduction of the L5 signal will allow user receivers to directly measure the delays induced when the signals traverse the ionosphere. As a result, achievable accuracy of the system will be much greater.

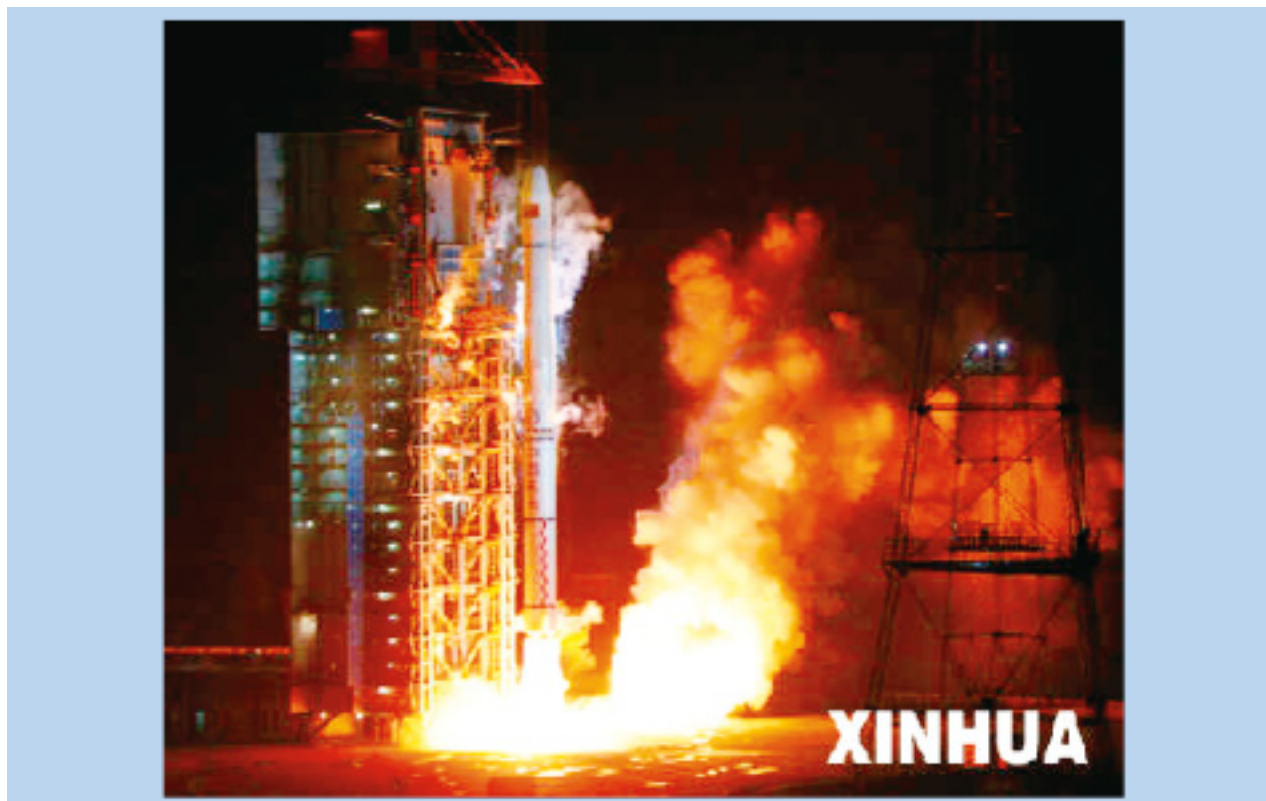
### 8.2.3 Modernized GLONASS

The Russian Federation has also been pursuing the modernization of its GLONASS system for several years. This ongoing activity will add new signals and frequencies for GLONASS civil users. It will also enhance the reliability of the GLONASS satellites and system as a whole.

### 8.2.4 Compass satellite navigation system

China launched a project to develop an independent satellite navigation positioning system in 1983, and began development of the Compass-G1 dual-satellite navigation system in 1994. In April 2004, Compass-G1 was completed and began to provide services for civil users. At present, it plays an increasingly important role in surveying, telecommunications, irrigation works, transportation, fisheries, prospecting, forestry and fire protection, emergency and disaster relief, national security, etc. The Compass-G2 satellite navigation system was developed beginning in 2006, and two satellites were successfully launched in April 2007 and April 2009.

Figure 8-4: Successful launch of the second Compass-G2 satellite



Development of the Compass-G2 system is divided into two phases. The first aims to build a regional satellite-based navigation satellite system consisting altogether of more than 10 geosynchronous earth orbit (GEO), inclined geosynchronous earth orbit (IGSO), and medium earth orbit (MEO) satellites. These mainly provide positioning, velocity, and time (PVT) services for China and surrounding regions. The estimated date of completion is 2011. The second phase is a global navigation satellite system consisting of over 30 GEO, IGSO, and MEO satellites, which enables global coverage and provides navigation positioning and communications services with positioning accuracy better than 10 meters. The anticipated date of completion is 2015.

It is expected that Compass-G2 will operate compatibly with GPS, GLONASS, and Galileo, and that they will together form a GNSS constellation consisting of over 120 observable satellites in orbit to enhance the accuracy, integrity, continuity, availability, and functions of GNSS navigation.

## 8.3 Navigation infrastructure planning strategy

### 8.3.1 Transition plan

The CAAC plans to transition from conventional to PBN navigation. PBN operations will rely primarily on GNSS. The CAAC will enhance research and applications of satellite-based navigation. Considering the safety and reliability of flight operations, some ground-based navigation aids will be retained, and ground-based navigation aids will also be added or changed in selected areas. Ground-based navigation aids will coexist with GNSS for a certain period of time and will serve as a backup to GNSS.

For en route operations supported by surveillance and communications capabilities, the CAAC will integrate en route navigation resources and establish ground-based redundant and backup navigation networks.

For the terminal area, the CAAC will ensure that equipment is available for expanded use of RNAV/RNP, and deployed as required for optimized RNAV/RNP approaches, and that ILS CAT I/II/III operational capabilities are maintained.

### 8.3.2 Ground-based navigation aids

- VOR—the CAAC will maintain a minimum VOR operating network to support the minimum route structure and conventional instrument flight procedures and provide backup navigation.
- DME—the CAAC will maintain and improve a DME/DME redundant network to support conventional instrument flight and RNAV operations based on requirements.
- ILS—the CAAC will improve deployment and construction of ILS, which is the primary navigation facility for landing operations at airports, and as appropriate will maintain and expand the scope of implementing ILS CAT II/III operation standards based on operational requirements.
- NDB—the CAAC will not build or equip new NDBs unless there is no other effective way or a special requirement exists.
- MLS—the CAAC will not adopt the MLS system.

### 8.3.3 GNSS navigation aids

- GNSS will be the primary navigation system for RNP operations in oceanic and remote airspace.
- GNSS will be the auxiliary navigation system in the continental route, terminal area, and for non-precision approaches and landings in the near term, and will evolve into the primary navigation system and support full RNAV/RNP operations in the medium and long term.
- Enhance the ground-based regional integrity monitor system (GRIMS) to monitor the integrity of the GNSS satellite signal.
- Improve RAIM prediction system to provide related service.
- GBAS system will be deployed for GLS approach at selected airports.



## SECTION 9

# Principles for a safe transition

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Due to limitations in conventional infrastructure and fleet capabilities, operations based on conventional navigation will coexist with PBN operations within a certain period in the future. The CAAC will mandate PBN operations at certain airports and to expedite the replacement of conventional operations. China is also aware that there are certain risks in PBN operations, such as mixed operations by aircraft with and without RNP capabilities; punctual design and update of routes and flight procedures to satisfy operational requirements; and the reliability and availability of satellite-based navigation. To ensure a smooth transition to PBN, the CAAC will take the following safety principles into consideration during its implementation:

- During the coexistence period, sufficient conventional navigations systems will be retained to provide services for aircraft without PBN equipage. The CAAC will take the requirements of the State aircraft into consideration, but will segregate traffic according to the navigation capability of the aircraft, and will grant preferred route access to aircraft with PBN capability.
- Operators will be given enough transition time to update their equipment. They and other airspace users are encouraged to install PBN avionics to become PBN-capable.
- The CAAC will conduct safety assessments and periodic safety inspections, and will formulate contingency plans to ensure continuous operational safety.
- Thorough operations monitoring will be implemented that will include operator qualifications, aircraft navigation performance, navigation error, etc., and corrective measures will be formulated as required.
- Harmonized conventional procedures and PBN flight procedures shall be considered in flight procedure design to reduce the risk of procedure conflict while conventional operations and PBN operations coexist.
- The air traffic control agency will enhance training of controllers, and will have control plans and safety measures in place for a blended operational environment to ensure safe separation.
- Operators shall be informed as early as possible before PBN operations are to be implemented at airports or en route, and airworthiness and operational approvals for Chinese operators shall be actively pursued.
- PBN operations will first be mandated at airports with operational requirements.
- The CAAC will coordinate with surrounding countries and areas to ensure compatible ATC separation minima and procedures in all the flight information areas (FIR) through which the main traffic flows.

## SECTION 10

## Future integration with other technologies

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PBN operations require the updating of communication and surveillance technologies in order to achieve greater benefits. During PBN implementation, the CAAC will promote the integration of navigation technology with communication, surveillance, and other new technologies.

### 10.1 Communication technologies

While it is anticipated that VHF voice capabilities will continue to be a vital part of the communication system of China's civil aviation for the foreseeable future, the increasing use of digital data communications is also expected. VHF digital link (VDL) and/or satellite communications (SATCOM) have been implemented in some parts of the world to support the following services:

- Airline operational communications (AOC)
- Air traffic services (ATS)

The long-term vision for ATM is ultimately 4D trajectory management for aircraft from takeoff to landing. For this vision, aircraft and ground-based systems will need to communicate via data link to negotiate planned flight routes and time. ICAO is developing the concept of required communication performance (RCP) and the R&D is under way.

The ICAO has made CPDLC part of the civil aviation communication services. CPDLC, a technology that allows digital messages to be sent back and forth between the controller and the flight crew, is also potentially valuable to PBN operations. The CAAC plans to implement RNP4 operations with CPDLC communication capabilities through VDL-based or SATCOM-based communication links for certain routes in Western China. The CAAC also plans to research and apply 4D trajectory management and realize continuous descent arrivals/approaches (CDA) during the medium term of PBN implementation.

### 10.2 Surveillance technologies

In the conventional ATC system, surveillance radar is used to monitor airplane operations and manage air traffic. This method requires a large number of ground-based radars for full coverage, incurring high construction and maintenance costs.

Automatic dependent surveillance (ADS) technology, including ADS-B and ADS-C, is an easier way with much lower construction and maintenance costs relative to radar.

- Automatic dependent surveillance-broadcast (ADS-B)

The aircraft position information, deriving from onboard GNSS receiver, is broadcast via VHF/UHF or satellite datalink and received by other aircraft nearby or ground receiving stations. Then the aircraft positioning and state vector data can be displayed on cockpit displays of traffic information (CDTI) and ground display terminals. Therefore, ADS-B can support both surveillance and information transfer.

- Automatic dependent surveillance–contract (ADS-C) system

Data link is used to report an aircraft's position in accordance with a contract. Along with CPDLC and GNSS-based RNP operations, ADS-C has transformed oceanic flight operations, reducing lateral separation standards by 50% and longitudinal standards by 75%. The ADS-C system and technology is now in use on the L888 route in western China for surveillance operations in non-radar environment.

The CAAC plans to gradually expand the use of ADS in the oceanic airspace, remote continental airspace, and airspace without radar coverage during the near term and medium term of PBN implementation, and will use ADS as the primary surveillance technologies in the long term.

## 10.3 Other approach and landing capabilities

### 10.3.1 Approach procedures with vertical guidance (APV)

ICAO defines three types of approach operations: non-precision approach (NPA), precision approach (PA), and APV.

APV is defined as an approach that has some form of vertical guidance but the performance does not meet the standards of a precision approach. RNP approaches that use baro-VNAV for vertical guidance are considered a type of APV approach. APV approaches can also be based on vertical guidance from GNSS in conjunction with an augmentation system such as SBAS. Prior to 2017, China plans only to implement APV approaches using baro-VNAV. Other options for APV approaches will be assessed as GNSS capability evolves.

### 10.3.2 GBAS landing system (GLS)

The ground-based augmentation system provides differential corrections, integrity information, and path definition data to aircraft via a VHF data broadcast (VDB) signal. GBAS supports two basic types of service:

- Approach services that provide guidance in the form of indications of deviations from a defined path in space known as the final approach segment (FAS).
- The GBAS positioning service (GBAS/PS), which provides position, velocity, and time (PVT) with improved accuracy, integrity, and availability for use by the flight management system (FMS) to support RNAV or RNP operations.

GLS is an airplane-level function based on use of GBAS in conjunction with other airplane systems to enable approach and landing capabilities. GLS is implemented such that it is similar operationally to ILS. In fact, cockpit operations and operational procedures are very nearly identical. However, the performance of GLS is improved relative to ILS in a number of ways that can provide benefits. For example, GBAS does not require protection of critical and sensitive areas on the runway or taxiways as is required for ILS. This means that aircraft taxiing on the ground will not disturb the guidance signals for airplanes on approach. Elimination of these critical and sensitive areas can result in more efficient use of runways at larger airports.

The GBAS/PS service may be used by the airborne equipment to enhance the availability of positioning to support RNAV/RNP operations. When the GBAS/PS is available, the airborne equipment is no longer required to perform RAIM to ensure integrity. This results in higher availability to support PBN operations that may include curved descending approaches.

The CAAC will select airports with operational requirements to implement GLS approaches and to support PBN operations requiring very high availability.

## SECTION 11

# Revision of PBN Roadmap

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This document is the first published version of CAAC PBN Roadmap. Updated versions will be published as needed. The CAAC welcomes suggestions and comments related to this PBN Roadmap.

## ANNEX A

# Introduction to PBN navigation specifications

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The performance-based navigation (PBN) concept combines three interrelated elements: the navigation specification, the navaid infrastructure, and the navigation application. Navigation specifications describe in detail the requirements placed on the area navigation (RNAV) system for operation along a particular route, and are used by States as a basis for certification and operational approval. The navaid infrastructure is the navigation infrastructure (e.g., space-based system or ground-based navigational aids) in support of each navigation specification. A navigation application is a navigation specification applied together with its associated navaid infrastructure either to en route, terminal area, or approach flight operations, or to operations within a defined operating area. Examples include RNAV/RNP routes, SID and STAR procedures, RNP approach procedures, etc. RNP is identical to RNAV except that RNP adds onboard performance monitoring and alerting. The numerals following the RNAV or RNP prefix represents the required navigation accuracy. For example, RNP-1 navigation specifications require that the aircraft meet an accuracy requirement of no more than 1 nautical mile from the nominal track in all directions 95% of the flight time.

The navigation specification, required navaid infrastructure, and navigation application as defined by ICAO shall be as follows:

RNP-10—designed for oceanic and remote continental areas, this concept is equivalent to RNAV-10. RNP-10 has been widely used internationally and does not in fact incorporate onboard performance monitoring or alerting function requirements. The RNP-10 navigation specification does not require any ground-based navaid infrastructure, but requires at least two sets of onboard long-range navigation systems (IRS/FMS, INS, GPS). It allows minimum lateral route spacing of 50 nautical miles (nm) where ground-based navigation aids, communications, and surveillance are available. At present, RNP-10 has been applied to the Sanya FIR of China.

RNAV-5—applies to continental routes, this RNAV application uses a variety of available navigation aids, both satellite and ground. The navigation sensor may be GNSS, DME/DME, VOR/DME, INS/IRS, or VOR. It normally requires radar coverage and direct voice communication. The RNAV-5 navigation specification is applied to Europe, Japan, and the Middle East.

RNAV-1/2—applies primarily to continental en route and terminal-area operations where radar surveillance and direct ground-to-air communication are available. The RNAV-1 navigation specification applies to en route as well as SID and STAR terminal-area operations. RNAV-2 applies to en route operations. The navigation sensor may be GNSS, DME/DME, or DME/DME/IRU. RNAV-1 SID and STAR procedures are in use at Beijing Capital Airport, Guangzhou Airport, Tianjin Airport, etc.

RNP-4—developed for operations in oceanic and remote airspace, this navigation specification requires voice communication or CPDLC and ADS-C to support the minimum route spacing of 30 nm. GNSS RAIM is used to ensure integrity. The RNP-4 application started in the Pacific region. China's L888 route employs RNP-4.

RNP-2—this proposed navigation specification is under study by the ICAO and remains to be defined.

RNP-1—includes Basic RNP-1 and Advanced RNP-1. Basic RNP-1 is applicable to en route and terminal-area operations. This basic specification is intended to allow connecting routes to be developed that link the en route environment with terminal areas having little or no radar coverage and a low-to-medium traffic density. GNSS is the primary navigation sensor for Basic RNP-1 and GNSS RAIM is used to ensure integrity. Strict safety assessment is required for use of DME / DME navigation based on RNAV. The Advanced RNP-1 specification is under study by the ICAO and remains to be defined.

RNP APCH—includes RNP approach procedures and RNAV (GNSS-based) approach procedures designed with a straight segment, the accuracy normally being 0.3. GNSS is the primary navigation service supporting RNP APCH procedures. The acceptability of the risk of loss of RNP APCH capability due to satellite failure or loss of the onboard monitoring and alerting function must be considered during procedure design. The missed-approach segment may be based on RNAV or conventional navigation procedures. The RNP APCH navigation specification does not include specific requirements for communication or surveillance.

RNP AR APCH—this RNP approach procedure requires special aircraft, aircrew, and approach procedure authorization by the regulatory authorities. It normally applies to airports where there is complex terrain and limited airspace, and thus where such flight procedure will lead to obvious benefits. Accuracy is normally between 0.3 and 0.1. Only GNSS is the allowed to be the navigation sensor. Achievable actual RNP precision shall be predicted. The specification excludes specific communication and surveillance requirements. At present, the RNP AR APCH navigation specification has been applied to Lahsa Airport, Linzhi Airport , Lijiang Airport, and so on in China.

Table A-1 Available navigation specifications for all phases of flight

Navigation specification	Phase of flight							
	En route oceanic/ remote area	En route Con- tinental	Arrival	Approach				Departure
				Initial	Inter- mediate	Final	Missed approach	
RNAV-10 (RNP- 10)	10							
RNAV-5		5	5					
RNAV-2		2	2					2
RNAV-1		1	1	1	1		1	1
RNP-4	4							
Basic RNP-1			1	1	1		1	1
RNP APCH				1	1	0.3	1	
RNP AR APCH				1-0.1	1-0.1	0.3-0.1	1-0.1	

## ANNEX B

## Glossary

ABAS	Aircraft-based augmentation system	ILS	Instrument landing system
ADS-B	Automatic dependent surveillance—broadcast	INS	Inertial navigation system
ADS-C	Automatic dependent surveillance—contract (also called ADS-A)	IRS	Inertial reference system
AOC	Airline operational communications	IRU	Inertial reference unit
APV	Approach procedure(s) with vertical guidance	NDB	Non-directional beacon
ATC	Air traffic control	PBN	Performance-based navigation
ATM	Air traffic management	RAIM	Receiver autonomous integrity monitoring
ATS	Air traffic services	RCP	Required communication performance
Baro-VNAV	Barometric vertical navigation.	RNAV	Area navigation
CDA	Continuous descent arrival Continuous descent approach	RNP	Required navigation performance
CNS	Communication, navigation, and surveillance	RNP AR APCH	RNP authorization-required approach
CPDLC	Controller-pilot data link communication	SARPs	Standards and recommended practices
DME	Distance measuring equipment	SATCOM	Satellite communications (voice or data link)
EASA	European Aviation Safety Agency	SBAS	Space-based augmentation system
FAA	Federal Aviation Administration (U.S.)	SID	Standard instrument departure
FIR	Flight information regions	STAR	Standard terminal arrival route (instrument arrival)
FMS	Flight management system	VOR	VHF omni-range (navaid)
Galileo	European global navigation satellite system		
GBAS	Ground-based augmentation system		
GLONASS	Global navigation satellite system of the Russian Federation		
GNSS	Global navigation satellite system		
GPS	Global positioning system		
ICAO	International Civil Aviation Organization		







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PERFORMANCE-BASED NAVIGATION IMPLEMENTATION ROADMAP