Doc 9992
AN/494

Manual on the Use of Performance-based Navigation (PBN) in Airspace Design

Approved by the Secretary General
and published under his authority

First Edition — 2013

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AMENDMENTS

Amendments are announced in the supplements to the *Catalogue of ICAO Publications;* the Catalogue and its supplements are available on the ICAO website at www.icao.int. The space below is provided to keep a record of such amendments.

RECORD OF AMENDMENTS AND CORRIGENDA

AMENDMENTS		
No.	Date	Entered by

CORRIGENDA		
No.	Date	Entered by

FOREWORD

The purpose of this manual is to provide step-by-step guidance on the application of performance-based navigation (PBN) in a development of an airspace concept. Originally developed as material to support the ICAO Airspace Concept Workshops for PBN Implementation, this manual can also be used by stakeholders involved in the implementation of PBN.

Airspace planners and designers need to understand the interdependence of the airspace concept with the navigation system capability and to view both in context with other enablers (communications (COM), surveillance (SUR) and air traffic management (ATM) procedures and tools). The benefits derived from the implementation of a PBN in an airspace concept must warrant the cost of aircraft and air traffic control (ATC) system equipage, pilot and ATC training, as well as airspace and procedure design arising from the implementation. This is achieved through careful planning which takes account of the detailed navigation functional requirements called up by the airspace concept and the timing of the implementation since costs are driven by the number of airframes that have to be retrofitted with updated navigation systems to meet the new requirements.

This manual is intended to supplement the existing procedures and guidance material on airspace design and planning found in:

Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444)

Procedures for Air Navigation Services — Aircraft Operations (PANS-OPS, Doc 8168);

Air Traffic Services Planning Manual (Doc 9426); and

Performance-based Navigation (PBN) Manual (Doc 9613)

Manual on Required Communication Performance (RCP) (Doc 9869).

Quality Assurance Manual for Flight Procedure Design (Doc 9906)

- Volume 1 — *Flight Procedure Design Quality Assurance System*

This manual also serves as an overlying and unifying reference document for the:

Continuous Descent Operations (CDO) Manual (Doc 9931); and

Continuous Climb Operations (CCO) Manual (Doc 9993).

Future developments

Comments on this manual would be appreciated from all parties involved in the development and implementation of airspace concepts for PBN implementation. These comments should be addressed to:

The Secretary General
International Civil Aviation Organization
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Montréal, Quebec, Canada H3C 5H7

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GLOSSARY

ABBREVIATIONS/ACRONYMS

ACC	Area control centre
AIM	Aeronautical information and mapping
AIRAC	Aeronautical information regulation and control
ANSP	Air navigation service provider
ATC	Air traffic control
ATM	Air traffic management
ATS	Air traffic service
CCO	Continuous climb operations
CDO	Continuous descent operations
CNS	Communications, navigation, surveillance
COM	Communications
DME	Distance measuring equipment
DTG	Distance to go
FDP	Flight data processor
Fpm	Feet per minute
FMS	Flight management system
FTS	Fast time simulation
GA	General aviation
GNSS	Global navigation satellite system
HMI	Human-machine interface
IAP	Instrument approach procedure
IFR	Instrument flight rules
INS	Inertial navigation system
IRS	Inertial reference system
LPV	Localizer performance with vertical guidance
NAV	Navigation
NAVAID	Aid to navigation
PBN	Performance-based navigation
RAIM	Receiver autonomous integrity monitoring
RDP	Radar data processor
RNAV	Area navigation
RNP	Required navigation performance
RT	Radio transmission
RTS	Real time simulation
SARPS	Standards and Recommended Practices
SID	Standard instrument departure
STAR	Standard instrument arrival
SUR	Surveillance
TLS	Target level of safety

TMA	Terminal control area
VFR	Visual flight rules
VOR	VHF omnidirectional radio range

DEFINITIONS

Airspace concept. An airspace concept provides the outline and intended framework of operations within an airspace. Airspace concepts are developed to satisfy explicit strategic objectives such as improved safety, increased air traffic capacity and mitigation of environmental impact, etc. Airspace concepts can include details of the practical organization of the airspace and its users based on particular CNS/ATM assumptions, e.g. ATS route structure, separation minima, route spacing and obstacle clearance.

Area navigation (RNAV). A method of navigation which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these.

Note.— Area navigation includes performance-based navigation as well as other RNAV operations that do not meet the definition of performance-based navigation.

Continuous climb operation (CCO). An operation, enabled by airspace design, procedure design and ATC, in which a departing aircraft climbs without interruption, to the greatest possible extent, by employing optimum climb engine thrust, at climb speeds until reaching the cruise flight level.

Continuous descent operation (CDO). An operation, enabled by airspace design, procedure design and ATC facilitation, in which an arriving aircraft descends continuously, to the greatest possible extent, by employing minimum engine thrust, ideally in a low drag configuration, prior to the final approach fix/final approach point.

Note 1.— An optimum CDO starts from the top of descent and uses descent profiles that reduce segments of level flight, noise, fuel burn, emissions and controller/pilot communications, while increasing predictability to pilots and controllers and flight stability.

Note 2.— A CDO initiated from the highest possible level in the en-route or arrival phases of flight will achieve the maximum reduction in fuel burn, noise and emissions.

Navigation aid (navaid) infrastructure. Navaid infrastructure refers to space-based and or ground-based navigation aids available to meet the requirements in the navigation specification.

Navigation application. The application of a navigation specification and the supporting navaid infrastructure to routes, procedures, and/or defined airspace volume, in accordance with the intended airspace concept.

Note.— The navigation application is one element, along with communications, surveillance and ATM procedures, which meets the strategic objectives in a defined airspace concept.

Navigation function. The detailed capability of the navigation system (such as the execution of leg transitions, parallel offset capabilities, holding patterns, navigation databases) required to meet the airspace concept.

Note.— Navigational functional requirements are one of the drivers for the selection of a particular navigation specification.

Navigation specification. A set of aircraft and aircrew requirements needed to support performance-based navigation operations within a defined airspace. There are two kinds of navigation specification:

RNAV specification. A navigation specification based on area navigation that does not include the requirement for on-board performance monitoring and alerting, designated by the prefix RNAV, e.g. RNAV 5, RNAV 1.

RNP specification. A navigation specification based on area navigation that includes the requirement for on-board performance monitoring and alerting, designated by the prefix RNP, e.g. RNP 4, RNP APCH.

Note.— The Performance-based Navigation (PBN) Manual (Doc 9613), Volume II, contains detailed guidance on navigation specifications.

Performance-based navigation. Area navigation based on performance requirements for aircraft operating along an ATS route, on an instrument approach procedure or in a designated airspace.

Note.— Performance requirements are expressed in navigation specifications in terms of accuracy, integrity, continuity, availability and functionality needed for the proposed operation in the context of a particular airspace concept.

RNAV operations. Aircraft operations using area navigation for RNAV applications. RNAV operations include the use of area navigation for operations which are not developed in accordance with this manual.

RNAV system. A navigation system which permits aircraft operation on any desired flight path within the coverage of station-referenced navigation aids or within the limits of the capability of self-contained aids, or a combination of these. An RNAV system may be included as part of a flight management system (FMS).

RNP operations. Aircraft operations using an RNP system for RNP navigation applications.

RNP system. An area navigation system which supports on-board performance monitoring and alerting.

Standard instrument arrival (STAR). A designated instrument flight rule (IFR) arrival route linking a significant point, normally on an ATS route, with a point from which a published instrument approach procedure can be commenced.

Standard instrument departure (SID). A designated instrument flight rule (IFR) departure route linking the aerodrome or a specified runway of the aerodrome with a specified significant point, normally on a designated ATS route, at which the en-route phase of a flight commences.

Chapter 1

BACKGROUND

1.1 PERFORMANCE-BASED NAVIGATION (PBN)

1.1.1 The ICAO Performance-based Navigation (PBN) Concept was introduced in 2008 and is detailed in the *Performance-based Navigation (PBN) Manual* (Doc 9613). The PBN concept replaced the required navigation performance (RNP) concept.

1.1.2 PBN introduces airworthiness certification and operational approval requirements for use of an RNAV system in airspace implementations. PBN is one of a number of enablers of airspace concepts, as shown in Figure 1-1.

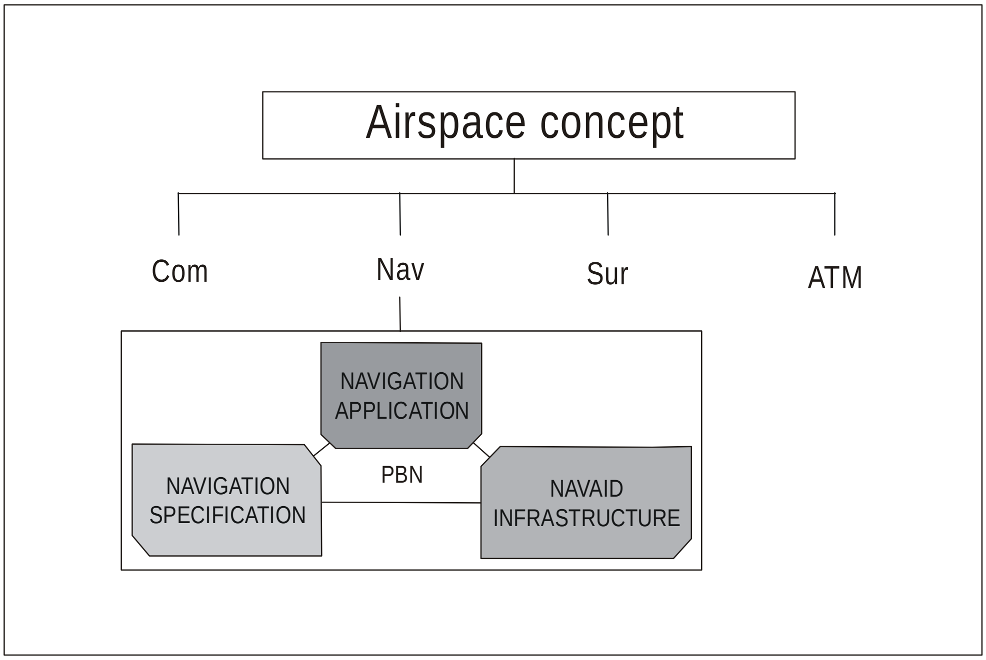

Figure 1-1 Airspace concept and PBN

1.1.3 The PBN concept relies on the use of area navigation. PBN consists of the following components:

a) navigation aid (navaid) infrastructure;

b) navigation specification; and

applying the above components in the context of the airspace concept to ATS routes and instrument procedures results in a third component:

c) navigation application.

The navigation application is key to the development of the airspace concept. The NAVAID infrastructure details the space or ground-based navaids required by the navigation specification used to support the navigation application. The navigation specification is a technical and operational specification that details the performance required of the RNAV or RNP system in terms of accuracy, integrity and continuity. On-board functionality, required navigation sensors, as well as the associated training and operating requirements are also spelled out. The navigation specifications are used by States as a basis for developing national regulations for PBN certification and operational approval.

1.2 THE AIRSPACE CONCEPT

1.2.1 The airspace concept describes the intended operations within an airspace and the organization of airspace to enable those operations. It includes many components of the ATM operational concept, including airspace organization and management, demand and capacity balancing, traffic synchronization, airspace user operations and conflict management. Airspace concepts are developed to satisfy explicit and implicit strategic objectives such as:

a) improved or maintained safety;

b) increased air traffic capacity;

c) improved efficiency;

d) more accurate flight paths; and

e) mitigation of environmental impact.

Airspace concepts can include details of the practical organization of the airspace and its users, based on particular communications, navigation, surveillance/air traffic management (CNS/ATM) assumptions; for2.3.2.33ffic service (ATS) route structure, separation minima, route spacing and obstacle clearance. Good airspace design and collaboration with all stakeholders (airspace planners, procedure designers, airlines, general aviation (GA), military, airport authorities, etc.) are critical to the effective implementation of an airspace concept (see Figure 1-2).

1.2.2 Once fully developed, an airspace concept describes in detail the target airspace organization and the operations within that airspace. It addresses all of the strategic objectives and identifies all the CNS-ATM enablers, as well as any operational and technical assumptions. An airspace concept is a master plan of the intended airspace design and its operation.

1.3 PBN BENEFITS

1.3.1 PBN offers many advantages over the historic, conventional navigation methods where instrument flight procedures and air routes were based upon specific ground-based navaids and their associated obstacle clearance criteria. Some advantages of PBN are:

a) it reduces the need to maintain sensor-specific routes and procedures and their associated costs;

b) it avoids the need for cost-prohibitive development of sensor-specific operations with each new evolution of navigation systems;

c) it allows for more efficient use of airspace (route placement, fuel efficiency, noise abatement, etc.);

d) it clarifies the way in which RNAV systems are used;

e) it facilitates the operational approval process for operators by providing a limited set of navigation specifications intended to form the basis of certification and operational approval material which could be applied globally in conjunction with the appropriate navigation infrastructure; and

f) it ensures that approval for operation in one State or region will be applicable in another State or region for those navigation applications calling up the same navigation specification.

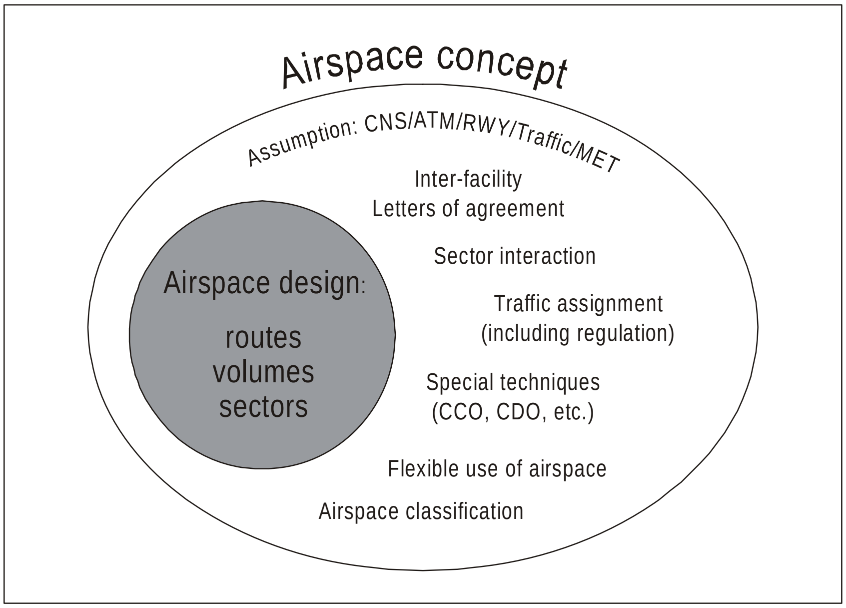

Figure 1-2 Airspace concept constituents

1.3.2 The development and implementation of an airspace concept using PBN makes significant contributions in terms of safety, environment, capacity and flight efficiency, for example:

a) the PBN partnership approach to developing the airspace concept ensures that conflicting requirements are processed in an integrated manner, and diverse interests are addressed without compromising safety, environmental mitigation, flight efficiency or capacity requirements;

b) safety is enhanced by ensuring that the placement of ATS routes and instrument flight procedures fully meet both ATM and obstacle clearance requirements;

c) environmental mitigation is improved when environmental needs are given the same level of importance as capacity enhancement when defining the operations in an airspace; and

d) airspace capacity and flight efficiency are enhanced by optimizing the lateral and vertical placement of both ATS routes and instrument flight procedures.

Chapter 2

PROCESS

2.1 INTRODUCTION

2.1.1 The development and implementation of an airspace concept can be broken down into four main phases: plan, design, validate and implement. Within these four main areas are 17 separate activities, see Figure 2-1.

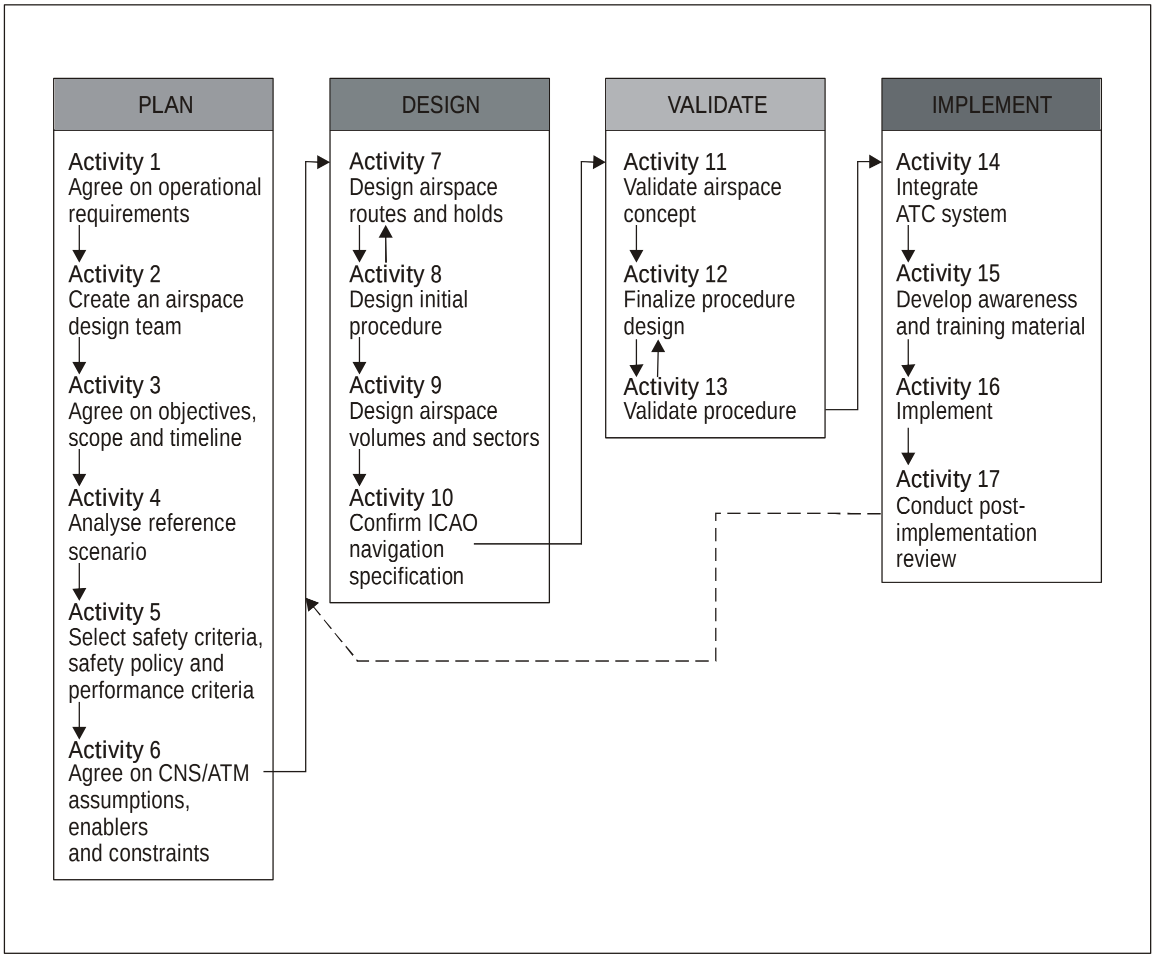

Figure 2-1. Airspace concept development and implementation process

2.1.2 Airspace redesign is usually initiated by an event which triggers an operational requirement. Such events are often categorized by one or more strategic objectives such as safety, capacity, flight efficiency, environmental mitigation or access. While some of these strategic objectives may be explicit in the proposed airspace change, the remainder will remain implicit objectives insofar as they should not normally be adversely affected by the proposed change. There are often conflicts between these objectives, and they must be prioritized, ensuring at all times that the maintenance of safety remains paramount.

2.1.3 There are two prerequisites to a successful airspace concept development:

a) comprehensive preparation — planning must take account of all aspects and must address all related stakeholder concerns; and

b) iteration — airspace development is not a linear process — it can only result in a sound product through a series of reviews, validations and subsequent refinements.

Success can only be achieved through comprehensive planning which establishes the scope and objectives of the airspace concept, based on the operational requirements.

2.2 PLANNING PHASE

2.2.1 Activity 1: Agree on operational requirement

Airspace changes are triggered by operational requirements, including the following examples:

a) the addition of a new runway or the extension of an old runway in a terminal area (e.g. to increase capacity at an airport);

b) pressure to reduce aircraft noise over a particular area (e.g. to reduce environmental impact over a residential area);

c) the need to support an expected increase in air traffic; or

d) updates of the CNS infrastructure to enhance operational safety and/or efficiency.

The requirements driving an airspace redesign should be clearly stated in a written document detailing strategic objectives so that subsequent work has a clear direction.

2.2.2 Activity 2: Create the airspace design team

2.2.2.1 In order to respond to the operational requirement identified in Activity 1, an airspace concept must be developed, validated and implemented. The airspace concept must address all of the requirements and cannot be developed by a single individual working in isolation. Airspace concepts, from inception to implementation, are the product of an integrated team working together — the airspace design team.

2.2.2.2 The airspace design team should be led by an ATM specialist with strong project management skills and an in-depth operational knowledge of the specific airspace under review. This ATM specialist would work in collaboration with:

a) air traffic controllers who are also familiar with operations in the airspace;

b) ATM and CNS system specialists who are familiar with the existing, and planned, CNS/ATM systems;

c) technical pilots from operators who use the airspace;

d) airspace designers and instrument flight procedure designers;

e) other airspace users (such as military, GA);

f) airport and environmental managers; and

g) experts from additional disciplines as deemed necessary, e.g. economists or data house specialists.

This is illustrated in Figure 2-2.

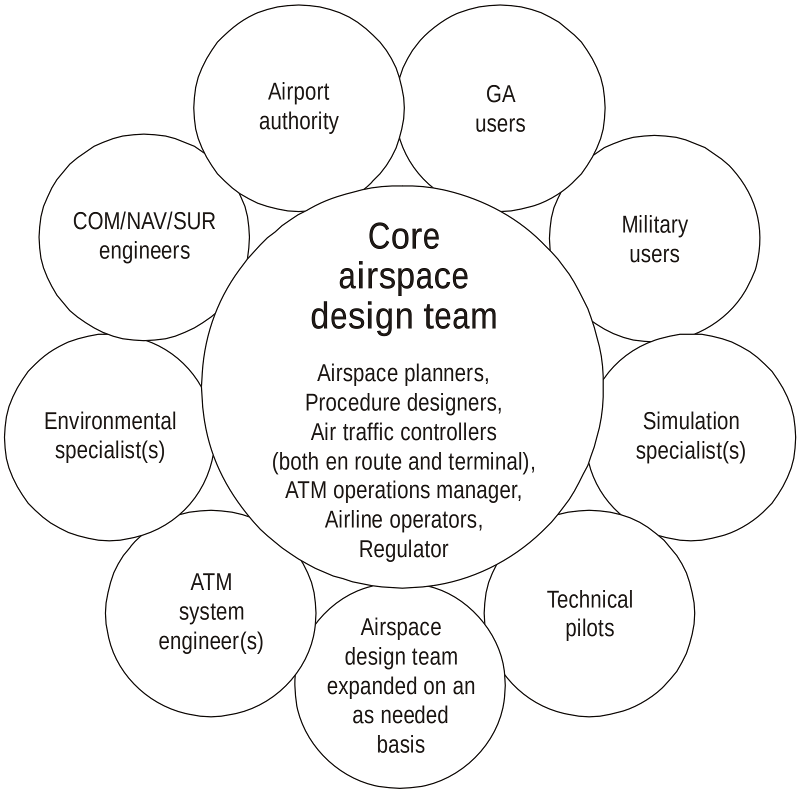

Figure 2-2 Airspace design team

2.2.3 Activity 3: Agree on objectives, scope and timelines

2.2.3.1 One of the first tasks of the airspace design team is to define and agree on the project objectives. These objectives should be derived from the strategic objectives that triggered the project. For example, if the project is triggered by an environmental strategic objective, the (airspace) project objectives might be linked to noise reduction (e.g. reduce the noise footprint over a nearby town). Another example may be a mandate from an authority requiring that certain changes be implemented. It is important that the project objectives be clearly specified in writing in order to assure that the reasons driving the change are satisfied.

2.2.3.2 Defining the project scope can be much more difficult. Limiting project scope to the minimum necessary to accomplish the agreed upon objectives is a good operating practice. Scope expansion is a risk in all projects, and uncontrolled scope expansion may increase timelines and costs to the point that the project is no longer viable. It is very important to decide what needs to be done to achieve the project objectives, and to agree and adhere to a specific body of work to accomplish these objectives.

2.2.3.2.1 The project scope is very much a function of time and human and financial resources available to complete the project. Two possibilities exist: either the team determines the implementation date based on all the work that needs to be completed, or the implementation date is fixed beforehand, and the team adjusts the scope or resources to match the time available.

2.2.3.2.2 Resources, time and scope are the three sides of the project-planning “triangle” (see Figure 2-3). Project scope is reviewed and may be iteratively modified throughout all phases of the airspace concept design. However, expansion of the project scope in later phases may tend to lengthen the project timeframe and/or increase the resources required, which may reduce the chance for project success. Such needs for expansion can be accommodated by phasing the project.

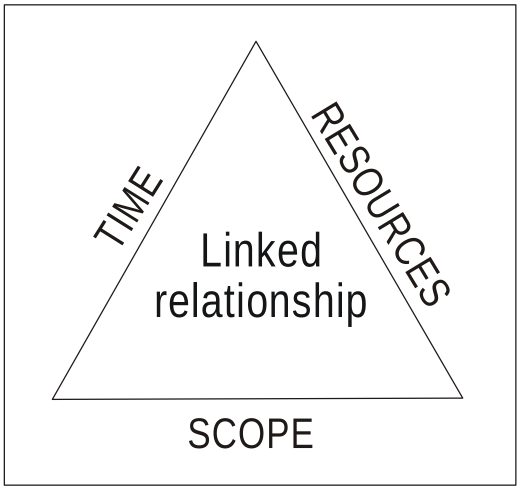

Figure 2-3. Planning triangle

2.2.3.3 It is important to ensure that the size of the major change to airspace structures, routes and procedures that the project generates is manageable on a regional basis. Step-by-step introduction of PBN airspace and routes over a number of years is more likely to meet with success than any all-encompassing, one-time approach. On the other hand, changes to the en-route structure often require changes to the adjacent terminal structure in the same aeronautical information regulation and control (AIRAC) cycle if connectivity is to be maintained. Nevertheless, coordination and planning with data houses are essential to avoid overloading those responsible for updating the navigation databases on board aircraft.

2.2.3.4 A sample project plan with time estimations is provided in Table 2-1.

Table 2-1. Example of a project plan

		Activity	*Number of days*
PLAN	1	Agree on operational requirements	10
	2	Create an airspace design team	5
	3	Agree on objectives, scope and timeline	15
	4	Analyse reference scenario	15
	5	Select safety criteria, safety policy and performance criteria	10
	6	Agree on CNS/ATM assumptions, enablers and constraints	12
DESIGN	7	Design airspace routes and holds	14
	8	Design initial procedure	20
	9	Design airspace volumes and sectors	20
	10	Confirm ICAO navigation specification	5
VALIDATE	11	Validate airspace concept	20
	12	Finalize procedure design	22
	13	Validate procedure	20
IMPLEMENT	14	Integrate ATC system	30
	15	Develop notification and training material	30
	16	Implement	1
	17	Conduct post-implementation review	30
		Total days required	279

2.2.4 Activity 4: Analyse the reference scenario

2.2.4.1 Before starting the design of the new airspace concept, it is important to have an appreciation of the current airspace situation. The reference scenario is a description of the current operations in the airspace where PBN is to be introduced and its purpose is to establish a baseline for development of a new airspace concept.

2.2.4.2 The reference scenario includes all the ATS routes, standard instrument departures/standard instrument arrivals (SIDs/STARs), airspace volumes (e.g. terminal control area (TMA)), ATC sectorization, air traffic data together with inter-centre and inter-unit coordination agreements. A sample reference scenario of a current airspace organization is shown in Figure 2-4.

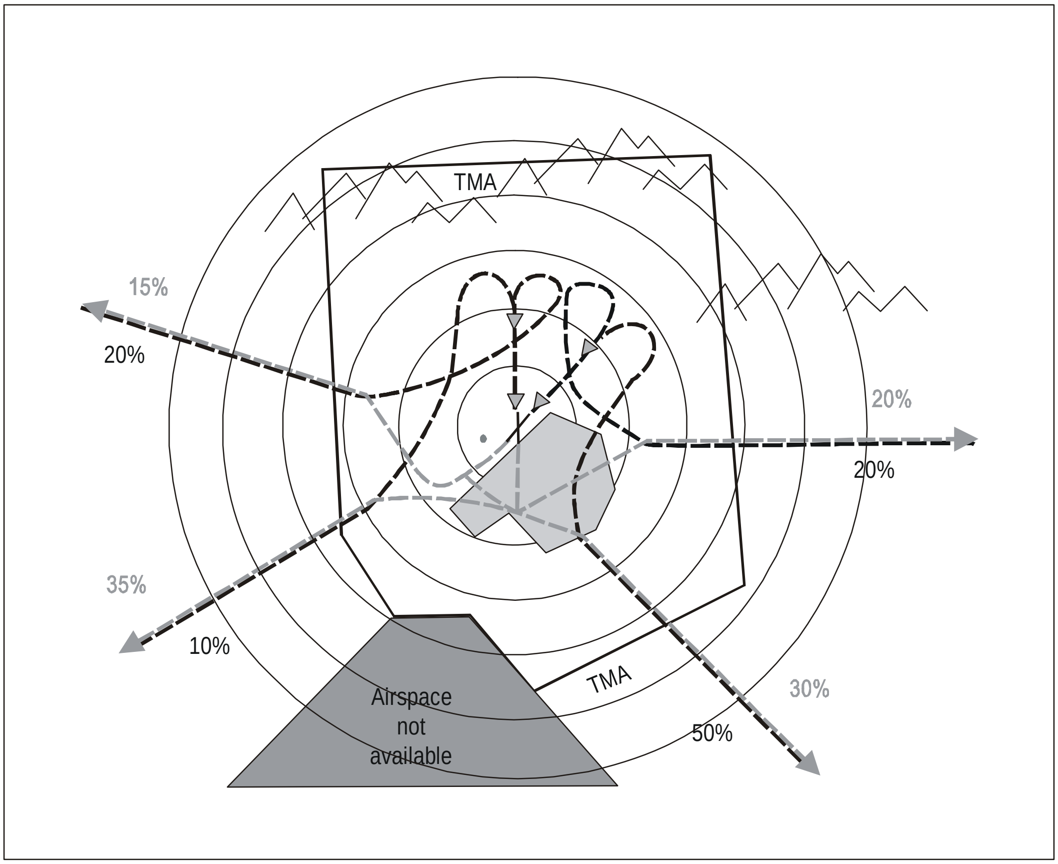

Figure 2-4. Example of a reference scenario

2.2.4.3 The description and analysis of the reference scenario is a critical step in the design process. By analysing the reference scenario in terms of the project's performance indicators, it is possible to gauge how the airspace is currently performing. It is also possible to determine with some certainty what works very well in an airspace and hence should be kept, and what does not work well or could be improved. Finally, and most importantly, by fixing the performance of the reference scenario, a benchmark is created against which the new airspace concept can be compared (see Figure 2-5). By using this benchmark it becomes possible to establish whether the proposed airspace concept performs better or worse than the reference scenario and whether the safety and performance criteria have been achieved. Analysis of the reference scenario may result in a need to update the project objectives or scope.

Note.— A one-to-one comparison of the different elements of the reference and new scenarios is not intended. It is the difference in the performance of the two scenarios that is compared.

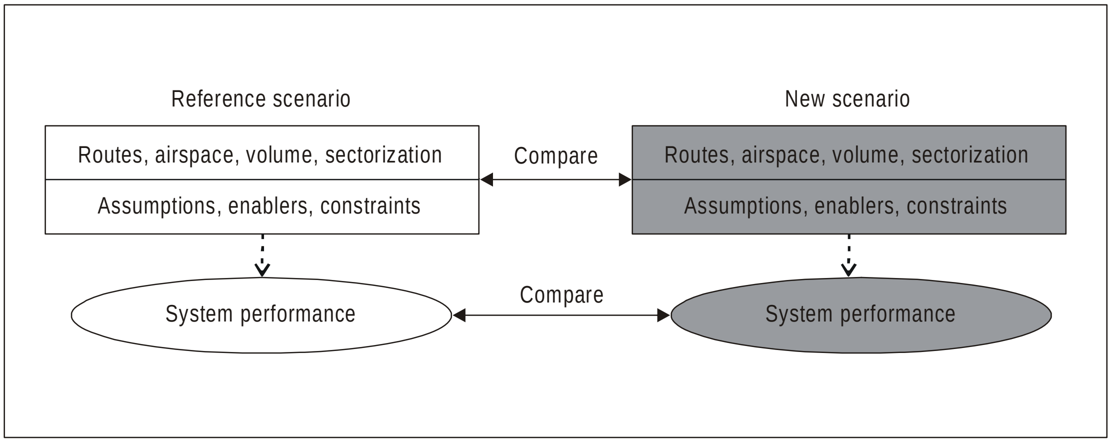

Figure 2-5. Scenario comparison

2.2.5 Activity 5: Select performance criteria, safety policy and safety criteria

2.2.5.1 The in-depth analysis of the reference scenario in Activity 4 provides direct input to the new airspace concept. The project objectives and scope may have been decided in Activity 3 (and/or updated by Activity 4), but it is still necessary to determine how to measure the project's success. For example, the project may be considered to be a success when its strategic objectives are satisfied — if the strategic objectives are to double the throughput on runway X, and this is demonstrated in a real time simulation (RTS) of the new airspace concept, then the project has satisfied this performance criterion.

2.2.5.2 Any airspace concept must meet the safety criteria laid down in the safety policy which has to be known at the outset of the project. Safety criteria may be qualitative or quantitative, and often a mix of both is used. The safety policy is normally promulgated at a national or regional level and hence is external to the project. If it is necessary to establish a safety policy at the project level, it is vital that it be approved at the highest possible national level early in the project's lifetime. Safety policy concerns itself with questions like:

a) Which safety management system should be used?

b) Which safety assessment methodology should be used? and

c) What evidence is needed to show that the airspace concept is safe?

2.2.6 Activity 6: Agree on CNS/ATM assumptions

2.2.6.1 The airspace concept to be developed is based upon certain CNS/ATM assumptions. These assumptions must take account of the environment that is expected to exist at the time when the new airspace operation is intended to be implemented (e.g. in 20XX). CNS/ATM assumptions include, for example:

a) the navigation capability of the aircraft expected to operate in the airspace;

b) the main runway in use within a particular TMA;

c) the percentage of operations that will take place during LPV;

d) the main traffic flows (in 20XX, the traffic flows may be different from current flows);

e) the ATS surveillance and communications systems that will be available in 20XX; and

f) ATC system-specific assumptions such as the maximum number of sectors that will be available for use.

These assumptions are highlighted in Table 2-2.

Table 2-2. CNS/ATM assumptions

Traffic analysis Representative traffic sample Distribution — time/geography Cross-check adjacent facility traffic Instrument flight rules (IFR) visual flight rules (VFR) mix Civil/military mix Aircraft performance mix (jet/turboprop/helicopter)	*Runway in use (primary/secondary)* Available runways/length Meteorological conditions Landing aids Greenfield site? Orientation choice? Runway usage statistics
Navigation Aircraft navigation equipage NAV infrastructure and coverage PBN conventional mix	*ATC system* Sectors/personnel/equipment Traffic sequencing and management
	Surveillance means/coverage Radar/ADS-B/MLAT/none
	Communications means/coverage Voice/datalink

2.2.6.2 The traffic assumptions will depend upon the anticipated fleet capabilities, and there should be a sound understanding of the likely traffic mix and distribution. This includes the mix of aircraft types (e.g. heavy and medium jets turboprops/helicopters/single-engine trainers); the mix of aircraft performance (minimum speeds, climb gradients, etc.) and the mix of operational roles (passenger, freight, training, etc.). In particular, the anticipated navigation capability of the fleet must be analysed:

a) How many of the aircraft have an RNAV system?

b) What primary positioning systems are used (global navigation satellite system (GNSS), VHF omni-directional radio range (VOR), distance measuring equipment (DME/DME)) by the RNAV systems?

c) Is an on-board augmentation inertial navigation system/inertial reference system (INS/IRU) fitted?

d) Against what standards have the RNAV systems been certified?

e) What operations are the aircraft and carriers approved for? and

f) What percentage of the fleet is not capable of the proposed PBN application?

2.2.6.3 It is important to establish the existing RNAV equipment approval, the actual capabilities and qualifications of the systems being carried and the system upgrades that are expected to be implemented prior to the introduction of the new airspace concept. It is costly for an operator to get approval of a specific RNAV capability and to maintain pilot currency in the operation of that capability. As a result, operators, and especially regional operators, will seek the minimum approval necessary to meet the existing navigation requirements for the airspace. If the new airspace concept calls up functionality that is present in the RNAV system software but is not covered in the existing certification, it will cost operators to gain approval and undertake the pilot training for this new functionality. However, this cost (and resulting implementation timescales) will be significantly less than if the aircraft requires retrofitting with new equipment or software.

2.2.6.3.1 A thorough knowledge of fleet capabilities and a realistic understanding of the likely improvements in capability that will be in place prior to the implementation date are required. Over-enthusiastic projections of fleet capability inevitably lead to major project delays and cancellations. For these reasons, it is important to communicate with aircraft operators and regulators to obtain a realistic estimate of future fleet capabilities and to undertake a realistic cost-benefit analysis throughout the project’s life cycle.

2.2.6.4 The project objectives together with the traffic assumptions and anticipated fleet capabilities are used to identify which existing ICAO navigation specifications can be applied to subsequent design phases. This specification is used as the basis for the subsequent airspace and procedure design. The navigation specification, airspace design, and procedure design steps are iterative in nature and may undergo several modifications before the navigation specification identified is finally confirmed in Activity 10.

2.2.6.5 The choice of traffic sample for the new airspace concept is as important as the knowledge of the fleet itself because the routes (ATS routes, SIDs/STARs or instrument approach procedures (IAPs)) should be placed in such a way as to ensure maximum flight efficiency, maximum capacity and minimum environmental impact (see Figure 2-6). Moreover, SIDs and STARs/approaches provide the link between the major en-route ATS routes and the threshold of the active runways (hence the importance of knowing the primary and secondary runway in use). A traffic sample for a new airspace concept is usually a future traffic sample, i.e. one where certain assumptions have been made about the fleet mix, the timing of flights, and the evolution of demand with respect to both volume and traffic patterns.

2.2.6.5.1 The success of an airspace concept can stand or fall on its traffic assumptions. Various models may be used to determine air traffic forecasts, and although the existing ATC knowledge of the air traffic movements can help considerably, the proposed traffic sample for 20XX must be thoroughly analysed, taking into account projections from all affected stakeholders. Invariably, certain characteristics will be identified in the traffic sample, e.g. seasonal, weekly or daily variations in demand, changes to peak hours, and the relationship between arrival and departure flows must all be taken into account in the airspace concept (see Figure 2-7).

2.3 DESIGN PHASE

2.3.1 Overview

2.3.1.1 Once the ATM/CNS assumptions have been agreed, the airspace design commences. For both en-route and terminal airspace, airspace design is an iterative process, which places significant reliance on the qualitative assessment and operational judgement of the controllers, pilots, airspace designers and procedure designers on the team.

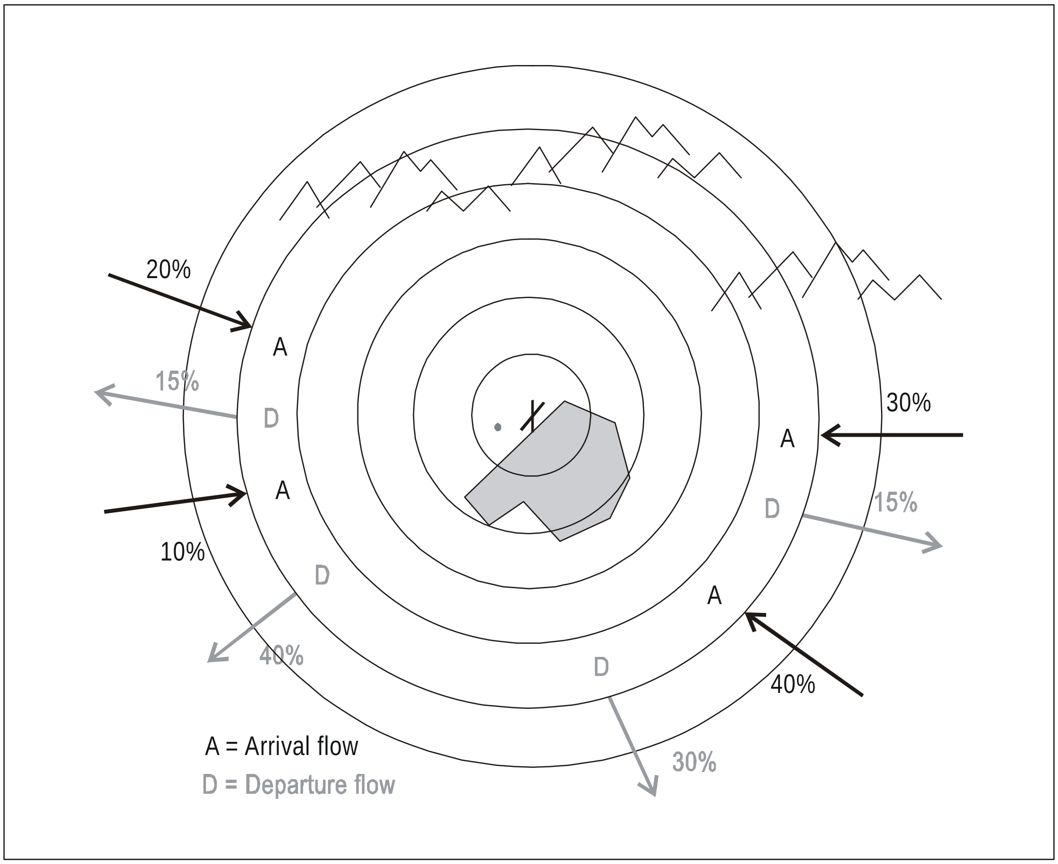

Figure 2-6. Example of future traffic assumptions

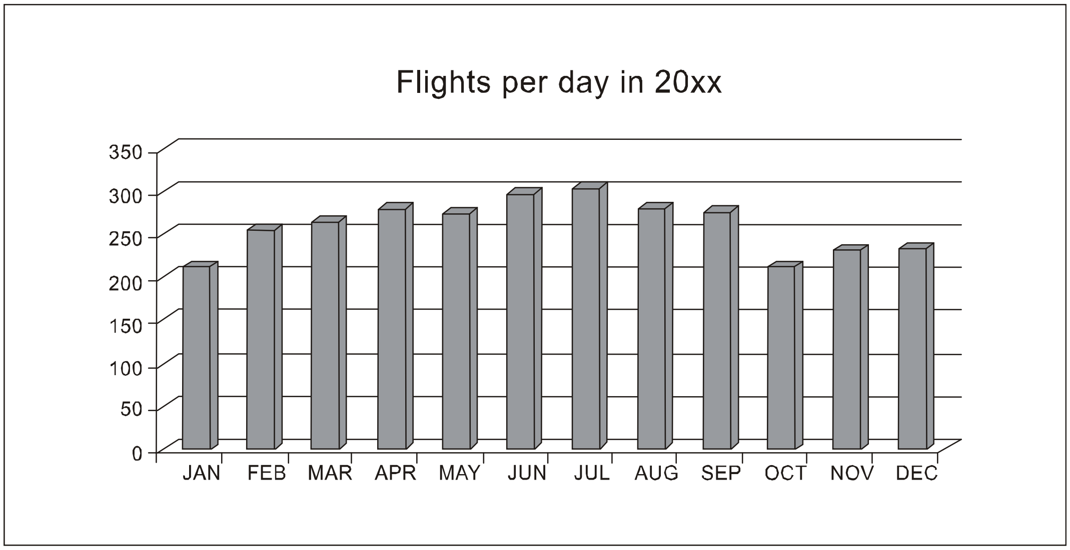

Figure 2-7. Example of traffic forecasts

2.3.1.2 It is critical to ensure coherence between en-route and terminal airspace — en-route designs must be fully integrated with the terminal designs.

2.3.1.3 The procedure designer must participate in the initial conceptual design led by the operational controllers, acting as a facilitator during this process and providing guidance on the proposed route placement from both an obstacle/airspace clearance and an aircraft performance perspective.

2.3.1.4 Technical pilots on the team are also crucial to the initial conceptual design because they provide the real aircraft performance information (e.g. related to climb/descent and turn performance) which is more effective than reliance upon theoretical computer models containing aircraft performance parameters.

2.3.1.5 First, the team designs the SIDs/STARs and ATS routes. This is an iterative analytical process, which starts at a conceptual level and develops into a detailed and rigorous design activity. It can be carried out using paper and pencil, particularly during the conceptual stage, and with software support, particularly during the detailed design stage. Route placement is usually determined by traffic demand, runways in use, strategic objectives and the constraints imposed by obstacles and airspace reservations. It may also be dependent upon the coverage provided by ground-based navaids, if such support is required (see Figure 2-8).

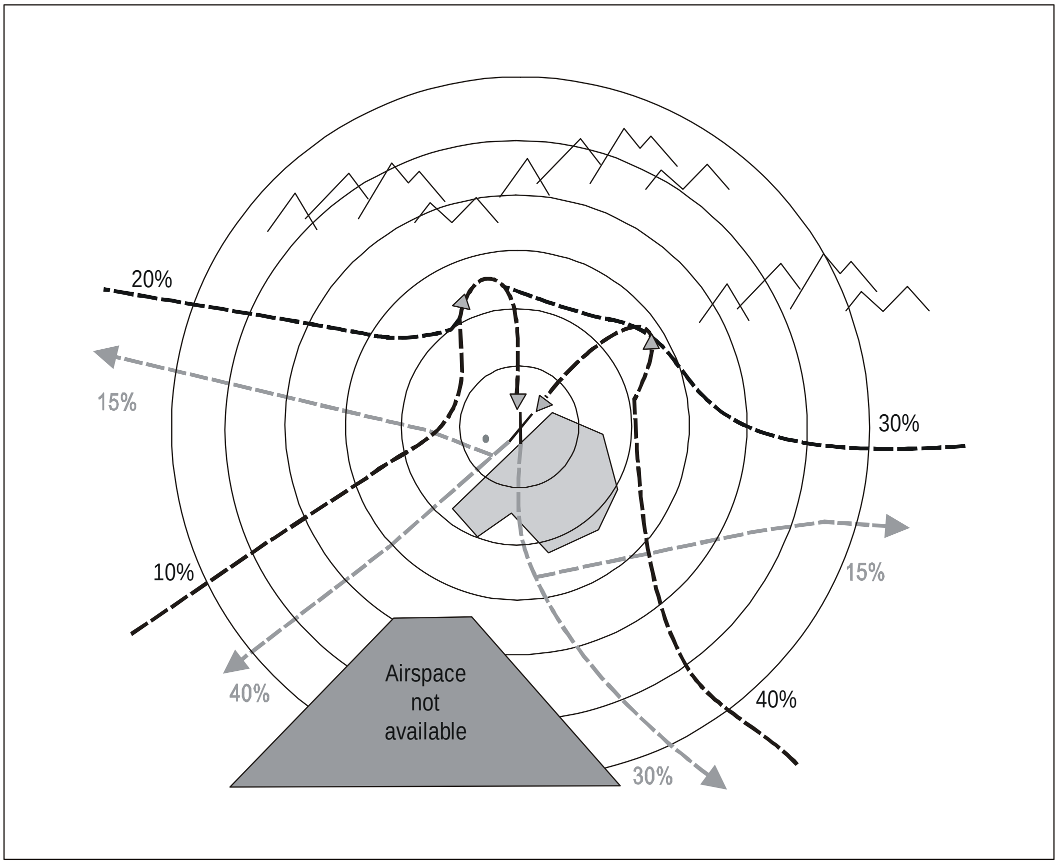

Figure 2-8. Example of a proposed airspace concept

Note 1.— The required route spacing and the available CNS infrastructure help to confirm whether the fleet capability of Activity 6 along with the preliminary choice from among existing ICAO RNAV or RNP specifications will support the proposed route design.

Note 2.— The role of the procedure designer in the terminal airspace route description and placement is of crucial importance. It is this specialist who advises the team whether the intended routes match the navigation specification assumptions and can be designed in accordance with PANS-OPS criteria.

2.3.1.6 After the routes have been designed and appropriate obstacle clearance is assured, an overall airspace volume is defined to protect all the IFR flight paths (TMA).

Note.— In regions where the entire airspace above a specified level is designated as controlled airspace, the definition of airspace volumes above such a level may be of minor application.

2.3.1.7 Finally, the airspace volume is sectorized for ATM purposes (see Figure 2-9).

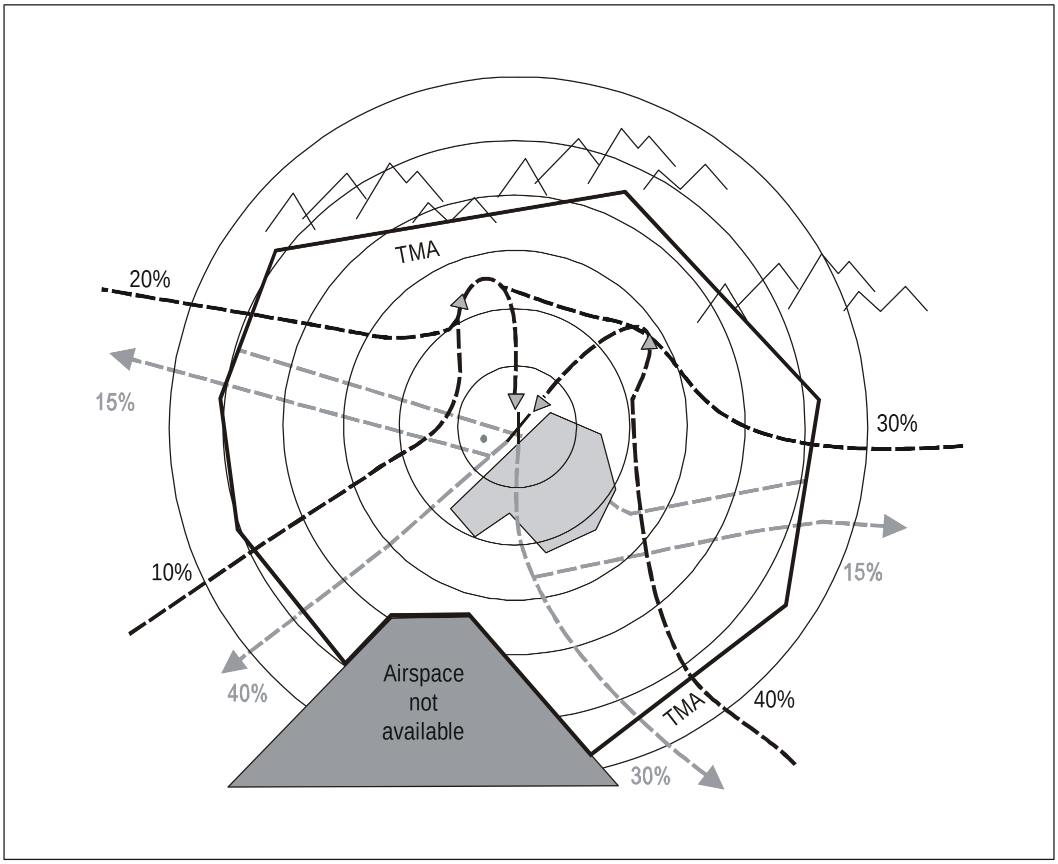

Figure 2-9. Example of an airspace concept with structure

2.3.1.8 The different activities and the iterative nature of the task means that there must be very close cooperation between all the stakeholders involved in the process (see Figure 2-10).

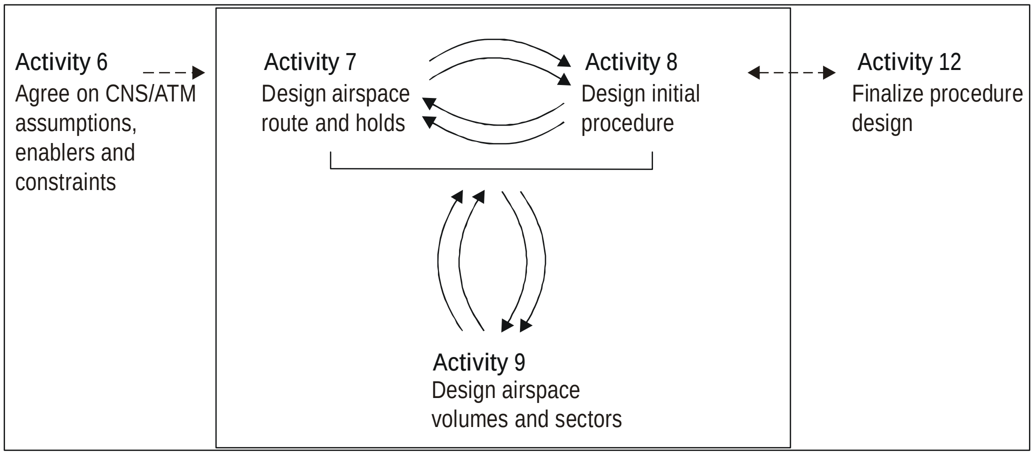

Figure 2-10. Design iterations

2.3.2 Activity 7: Airspace routes and holds

2.3.2.1 PBN makes it possible to place routes in the most optimum locations as long as the necessary coverage is provided by the ground- or space-based navigation aids. This means that routes can be placed so as to:

a) optimize capacity by avoiding conflicts between traffic flows in both the lateral and vertical plane;

b) improve operational efficiency with shorter route lengths;

c) support continuous descent operations (CDO) or continuous climb operations (CCO) with vertical windows and thereby enable more fuel-efficient profiles with reduced environmental impact (noise, greenhouse gas emissions, etc.);

Note.— CDO is addressed in detail in the Continuous Descent Operations (CDO) Manual *(Doc 9931) and CCO is covered in the* Continuous Climb Operations (CCO) Manual *(Doc 9993).*

d) avoid noise-sensitive areas;

e) avoid bidirectional traffic on the same route with parallel routes;

f) provide different route options between two airports;

g) enhance airport accessibility; and

h) improve operational safety.

Most significantly, PBN makes efficient connectivity between en-route and terminal procedures possible, thereby ensuring a seamless continuum of routes. All of these advantages do not negate best practices in route design developed over decades. Some of these considerations are provided below.

Note.— In the following paragraphs, the term "ATS routes" refers to those routes usually designated as per Annex 11, Appendix 1 (e.g. UL611), whilst "terminal routes" refers to IAPs and SIDs/STARs designated in accordance with Annex 11, Appendix 3 (e.g. KODAP 2A) and Annex 4, Chapter 11.

2.3.2.2 ATS route networks cover most of the world's continents and reflect the main traffic flows across the landmasses. The ATS route network should be planned at a continental, regional or area level as appropriate. This invariably results in a more efficient route network and avoids potential conflicts between traffic flows.

2.3.2.3 Route spacing, which plays a major role in determining the capacity of an airspace, is very dependent upon the CNS/ATM infrastructure supporting the operation. For example, where RNAV 5 has been implemented in high-density European airspace, a route spacing of 10–15 NM can only be achieved if adequate radar surveillance is available, and the ATM infrastructure supports controller monitoring of track behaviour. Route spacing is also affected by the geographical situation of the relevant airspace, the main traffic flows and the amount of mixed traffic operations. Some route spacing criteria may only address the distance between parallel straight segments and do not take into account the variable turn performance of different aircraft at different altitudes. Many aircraft limit bank angle when above FL190, and this can lead to turns being initiated up to 20 NM before a fly-by waypoint. In order to achieve track segregation during turns, it is necessary to either require all aircraft to have the ability to follow fixed radius turns or to increase the route spacing significantly at the turn points. Alternatively, the spacing between the parallel curved paths must be increased on the turns.

2.3.2.4 Continental traffic flows service multiple airports, and in order to avoid mixing overflying traffic with climbing and descending traffic, designers should aim to segregate the ATS routes (black) from the terminal routes to/from airports (grey/dashed lines) (see Figure 2-11).

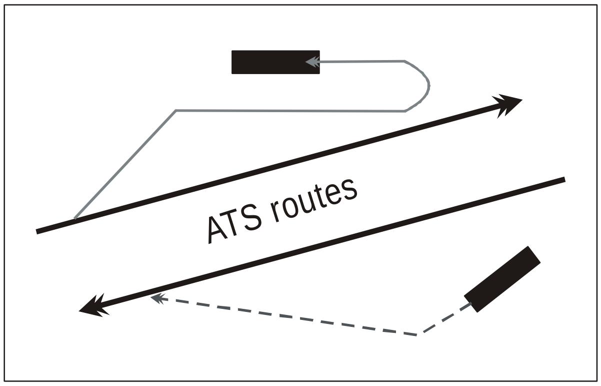

Figure 2-11. Segregated routes

2.3.2.5 While operators and environmental managers concentrate on the placement of each terminal route in terms of flight efficiency, environmental mitigation and obstacle clearance/flyability, ATC has to manage the traffic along all the routes as a package. The airspace design, from an ATC perspective, concentrates on the interaction between the arrival and the departure flows. These different objectives are not mutually exclusive. It is possible to design terminal routes and achieve most of the, apparently conflicting, objectives. Care must be taken in selecting the departure and arrival route crossing points to ensure that neither arriving nor departing aircraft are constrained. It is important to have a good understanding of the fleet performance. The graph in Figure 2-12 shows the conflict zones for 3 per cent, 7 per cent and 10 per cent climb gradients (blue), and 3- and 2-degree arrival profiles (green) at various distances from the runway.

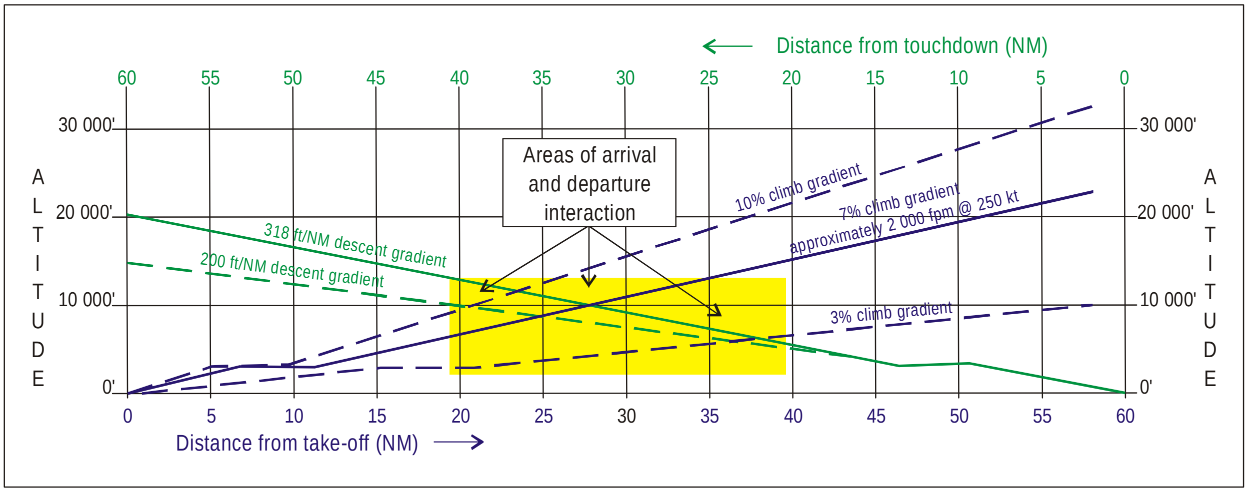

Figure 2-12. Vertical interaction

Example: A departure on a 7 per cent climb gradient (solid blue line) 25 track miles from the runway will conflict with the arrival (green-hashed line) at 35 track miles from the threshold, when both aircraft would be in the region of 9 000 ft above aerodrome elevation. A crossing point at this location would hamper both the departure and the arrival.

2.3.2.6 There are currently three ATM “practices” or “models” that can be observed in the design of busy terminal airspaces. The first involves a number holds which is used to keep the pressure on the terminal airspace by feeding a continuous stream of arriving traffic from the holding stacks to the arrival/approach system. The second model is more elastic in that, in order to avoid holding aircraft, longer terminal arrival routes are designed to the landing runway. The third model pre-plans advanced sequencing through a manual or automated arrival management system that adjusts departure and/or en-route flight times to maintain a balanced stream of aircraft at designated terminal arrival points. Early linear extensions on extended PBN routing or use of ATM arrival management tools allow the pilot to better plan the descent profile and hence provide benefits over low altitude terminal holding.

2.3.2.7 PBN STARs may be designed as arrival procedures with “open” or “closed” paths (see Figure 2-13). Open STARs provide track guidance to a downwind track position from which the aircraft is tactically guided (vectored) by ATC to intercept the final approach track. Closed STARs provide continuous track guidance to the final approach track for an automatic transition to final approach, and because the aircraft is always on a defined path, provide excellent predictability for both pilot and controller. In the closed STAR, the RNAV system always has a defined distance to touch down, which allows automated management of the vertical profile, thus enabling maximum flight efficiency. A closed STAR can also be designed and published in a manner that facilitates alternative routing by ATC on a tactical basis through the provision of additional waypoints to provide path stretching or reduction. Any tactical change will impact the vertical profile if it is delivered after the aircraft has reached “top of descent”. An open STAR requires tactical routing (vectoring) instructions to align the aircraft with the final approach track. The RNAV system may manage the descent to the final point on the STAR prior to the ATC intervention but cannot ensure a CDO profile as the flight management system (FMS) has no knowledge of the likely track miles to be covered under tactical routing. Advance planning by the pilot is also more difficult when using an open STAR, though ATC flexibility is increased.

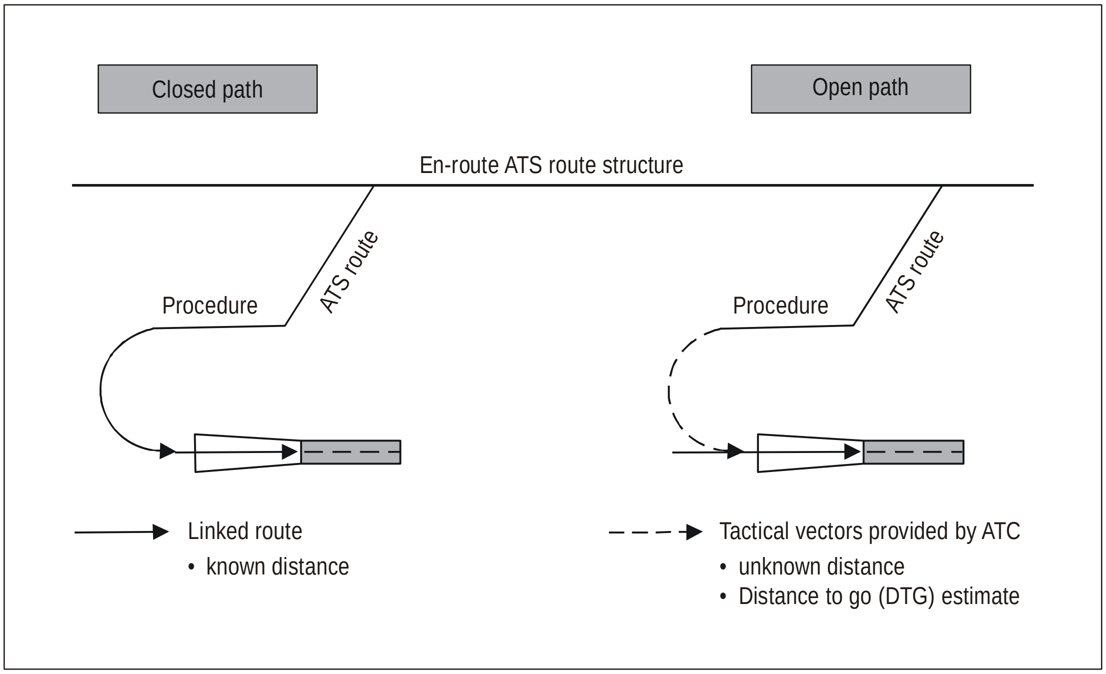

Figure 2-13. Different STAR methodologies

2.3.2.8 Where multiple arrival routes are operated into an airport, sequencing can represent a challenge to ATC. Within an airspace the mix of conventional and PBN-qualified aircraft may vary. The choice of open STAR or closed STAR must take account of the operating environment, ATC procedures and available sequencing tools. ATM methods are being developed to allow efficient sequencing of mixed fleets of aircraft on multiple CDO arrival routes and include:

a) *point merge* — a method using an open STAR design that seeks to maintain a high degree of ATC flexibility and control by use of level segment "lateral holding arcs" (see Figure 2-14);

b) *structured decision points* — a method that uses a closed path STAR to maintain an efficient descent path whilst allowing ATC the advantage of sequencing aircraft well in advance. It does this by taking advantage of the fact that in a closed path STAR the exact distance to the runway is always known. Waypoints on different STARs are then created equidistant from the airport. The controller uses these equidistant waypoints to verify separation and take advance, predefined actions to adjust separation if necessary (see Figure 2-15);

c) *defined interval* — a method being developed that uses dynamic risk-based analysis to improve separation methods and allow for an increase in capacity. Defined interval requires a high degree of automation to provide feedback to both the pilot and controller allowing the maintenance of a defined safety level to be associated with each trajectory decision; and

d) *required time of arrival* — a method being developed to assign aircraft specific arrival times well in advance over outlying airspace waypoints. These time assignments allow advance planning by the pilot for efficient speeds and also maintain a balanced arrival flow to the airport, thus eliminating the need for holding upon arrival while also allowing for a closed path CDO.

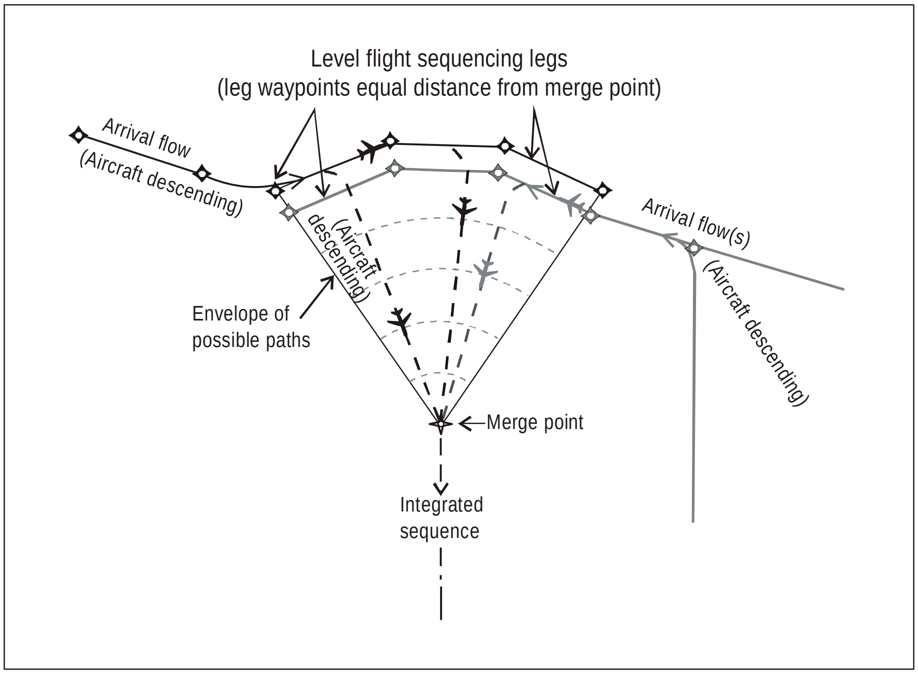

Figure 2-14. Example of point merge design

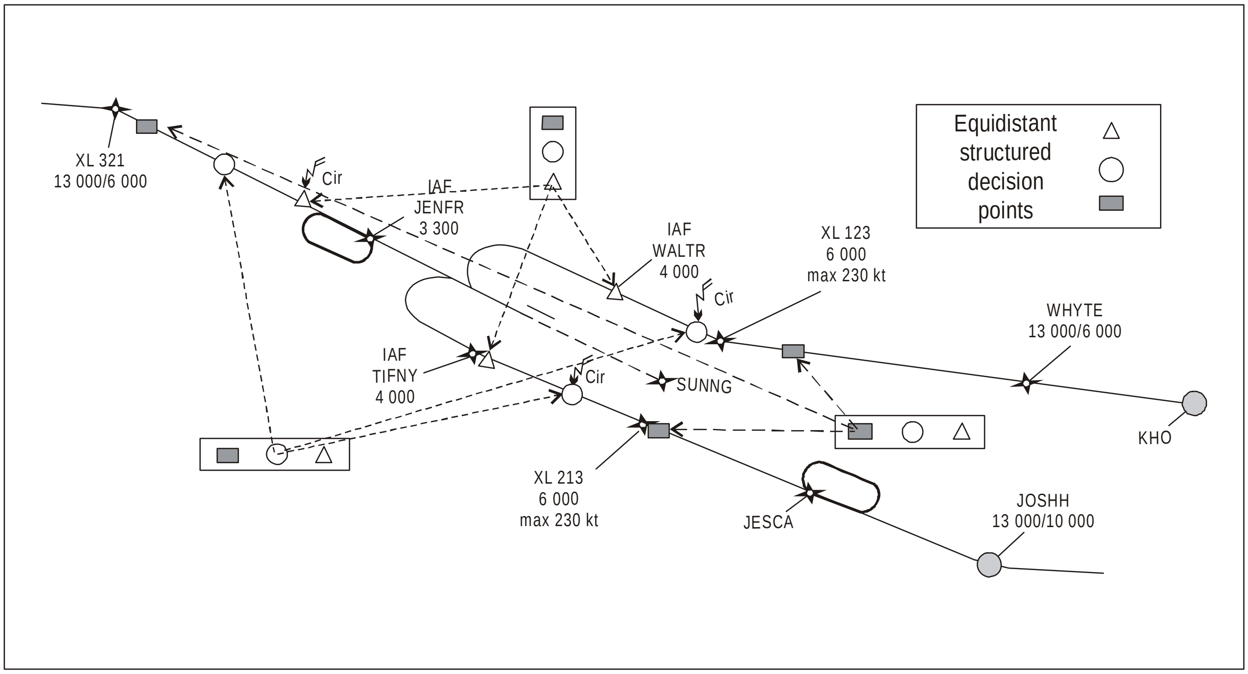

Figure 2-15. Structured decision points

2.3.3 Activity 8: Initial procedure design

2.3.3.1 The preliminary procedure design runs in concert with the airspace design and comprises four steps:

a) first the airspace design is analysed to confirm which navigation performance is needed to achieve the intended design;

b) then the fleet capability is analysed to determine whether it meets the navigation performance required by the intended design;

c) the NAVAID infrastructure is then analysed to establish whether the NAVAID coverage is sufficient to support the intended design — if ground-based navigation aids are expected to be used, the availability and coverage of these aids should be ascertained before a major design commitment is made; and

d) the proposed routes and holds are analysed to establish whether they are feasible, taking account of the navigation performance needed (see b) above), the available NAVAID coverage, the appropriate route spacing criteria and the obstacle constraints.

2.3.3.2 If the fleet capability or the navigation infrastructure is inadequate, it may be necessary to identify trade-offs and that may mean changing the airspace concept. If the routes are shown to be unfeasible, the airspace design will have to be reconsidered.

2.3.3.3 The choice of navigation performance can be made early in the design process based upon the decisions made in Activity 6. As the design becomes more specific, the procedure designer in the airspace design team should clarify whether certain functionalities would be required and expected to be available.

2.3.4 Activity 9: Airspace volumes and sectorization

2.3.4.1 The design of ATS routes, terminal routes, airspace structures and ATC sectorization is an iterative process. The airspace structures and the ATC sectorization are considered once the ATS and terminal routes have been completed. The airspace structure is created to protect IFR flight paths, both vertically and laterally, and it may be necessary to modify the routes to ensure that they fit within the airspace structure. Once the structure is complete, the airspace is sectorized for ATM purposes and again it may be necessary to revisit the route placement. Neither structures nor sectors need, of necessity, follow national borders. It is possible, and even desirable for reasons of flight efficiency and capacity, to design cross-border airspace structures or sectors. In such cases, the delegation of ATS will need to be considered.

2.3.4.2 Airspace sectorization may be functional or geographic:

a) in geographical sectorization the airspace volume is divided into 3D blocks where a controller is responsible for all traffic within the block (sector); and

b) in functional sectorization the airspace is structured by function of an aircraft’s phase of flight. For example, in terminal airspace, one controller may be responsible for arriving aircraft and another may be responsible for departing aircraft in the same 3D airspace block.

2.3.4.3 En-route airspace tends to be sectorized in a geographic manner while terminal airspace may use one or both types of sectorization (see Figure 2-16). In many units, a hybrid of functional and geographic sectorization is used.

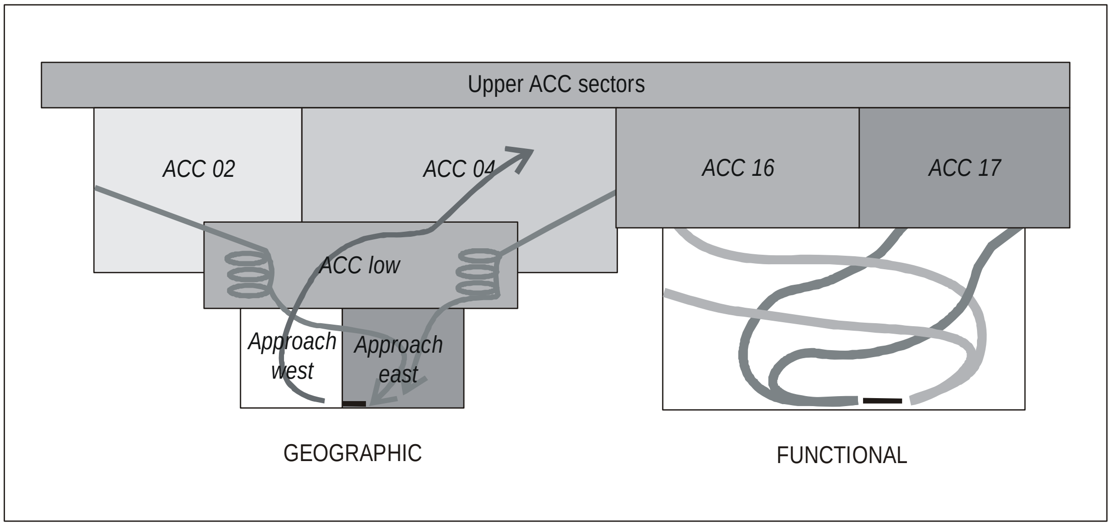

Figure 2-16. Examples of sectorization

2.3.5 Activity 10: Confirming the ICAO navigation specification identified in Activity 6

2.3.5.1 The activity is the confirmation of the navigation specification from the PBN manual that matches, in terms of navigation performance/functionality, the requirements of the airspace concept. This can be difficult to achieve which is why the importance of a rigorous analysis of the aircraft fleet in Activity 6 is emphasized. As it is rarely cost-effective to require a significant proportion of the fleet to retrofit RNAV systems or sensors to achieve a specific functionality, it is crucial that design Activities 7 to 9 be kept within the limits of the existing aircraft capability. The European introduction of RNAV 5 provides a useful example of how expectations had to be “downgraded” as a result of fleet equipage. In the 1990s, the initial intent was to implement RNAV 1, but this had to be scaled down to RNAV 5 when it became clear, three years before the implementation date, that the expected natural replacement of the older equipment with systems compatible with RNAV 1 was much slower than expected and that retrofits would be too costly.

2.3.5.2 If a mandate is applied, then all aircraft flying in the airspace will be capable of flying the new routes/procedures. However, the benefit of a mandate must be shown to outweigh the cost of implementation.

2.3.5.3 One option may be to consider a mixed navigation environment involving one or more PBN navigation specifications and some traffic using conventional navigation. Mixed navigation environments usually occur in one of three scenarios:

a) a PBN application is implemented, but not mandated, and conventional navigation is retained;

b) a “mixed mandate” is used within an airspace volume — usually en-route or in oceanic/remote procedural operations where an RNAV application is required for operation along one set of routes or altitudes, and an RNP application along another set of routes or altitudes within the same airspace; or

c) a mix of RNAV or RNP applications is implemented in airspace, but there is no mandate for operators to be able to perform them. Here again, conventional navigation could be authorized for aircraft that are not approved for any of the navigation specifications.

2.3.5.4 Mixed navigation environments can have a negative impact on ATC workload, particularly in dense en-route or terminal area operations. The acceptability of a mixed navigation environment is also dependent on the complexity of the ATS route or terminal route structure, the procedure design, and the availability and functionality of ATC support tools. The increased ATC workload can result in the need to limit mixed-mode operations to a maximum of two types where there is one main level of capability. In some cases ATC may only be able to accept a mixed environment where a high percentage (70–90 per cent) of the traffic is approved to the required navigation specification. For these reasons, it is crucial that operations in a mixed navigation environment be properly assessed in order to determine the viability of such operations.

2.4 VALIDATION PHASE

2.4.1 Overview

Once the airspace design is complete, the airspace concept will have become a comprehensive body of work that needs to be validated and checked. Validation takes place in various phases:

a) the airspace concept is usually validated during the design process and again when the airspace design is complete; and

b) the new routes are validated once the design process is complete.

Note. — The following section addresses validation of the airspace concept and the airspace design. The validation of instrument flight procedure design is addressed in Doc 8168, Procedures for Air Navigation Services — Aircraft Operations, *Volume II —* Construction of Visual and Instrument Flight Procedures *and in the* Quality Assurance Manual for Flight Procedure Design *(Doc 9906)*.

2.4.2 Activity 11: Airspace concept validation

2.4.2.1 The main objectives of the airspace concept validation are to:

a) assess whether the project objectives can be achieved by implementation of the airspace design and the airspace concept in general and that there is a positive business case;

b) prove the ATM validity of the airspace design;

c) identify potential weak points in the concept and develop mitigation measures; and

d) provide evidence that the design is safe, i.e. to support the safety assessment.

2.4.2.2 Validation methods may produce quantitative or qualitative results. Both types of results are needed, and the validations are undertaken at the same time as they each need information produced by the other method. It is essential that the results be viewed as a single entity even if they are derived from significantly different methods. In general terms, quantitative assessment refers to validation methods that are numerical and rely on the quantification of data. These methods usually rely on tools that are usually computer-based simulators. Qualitative assessment is not reliant on data but more on objective analysis, reasoning, argument and justification. However, data from a quantitative assessment cannot be accepted without analysis either, and thus the final result depends on the effective use of the qualitative assessment tools. Table 2-3 provides a comparison of the different modelling methods.

Table 2-3. Example of model comparison

	Sample input	*Assessment bench mark used*	*Output*	*Validation method*
Qualitative Assessment	Published and proposed airspace design (routes/holds, structures and sectors).	Non-numerical performance and safety criteria based upon ICAO SARPs, procedures and guidance material and national/local regulations.	Mainly textual/ diagrammatic reasoning, argument, justification.	– Expert CNS/ATM judgement – Airspace modelling
Quantitative Assessment	Published and proposed airspace design (routes/holds, structures and sectors) usually in computer data format representing airspace organization and traffic samples. Surveys — radar data recordings, flight plan recordings, flight recordings, questionnaires. Statistics and forecasts — airport operations statistics, meteorological data collections, traffic demand, traffic distribution.	Absolute numerical performance and safety criteria based upon performance and safety criteria based upon ICAO SARPs, procedures and guidance material and national/local regulations.	Numerical data (primarily).	– Airspace modelling – FTS/RTS – Live ATC trials – Flight simulation – Data analytical tools – Statistical analysis – Collision risk modelling – Noise modelling

2.4.2.3 As shown in Table 2-3, several ways in which to undertake airspace concept validation are:

a) airspace modelling;

b) fast time simulation (FTS);

c) RTS;

d) live ATC trials;

e) flight simulation;

f) data analytical tools;

g) statistical analysis;

h) collision risk modelling; and

i) noise modelling.

2.4.2.4 Each method differs in terms of cost, realism, complexity, time and the number of traffic samples and test cases used. The more complex the simulation method used, the greater the cost, the longer the preparation/run time required and the closer to reality the results become. However, normally for reasons related to cost/time, the number of traffic samples/test cases tend to decrease as the complexity of the simulation method used increases (see Figure 2-17).

2.4.2.5 Most computer-based validation tools assume an unrealistically high quality navigation performance on the part of the aircraft, but this does not usually affect the main aim of the validation exercise which is to check the ATM workability and the safety of the proposed airspace concept. Where a specific investigation into the impact of navigation failure modes is desired, the simulation scenarios will require additional preprogramming. It should be noted that the route spacing criteria already take account of navigation failure modes, and most airspace concepts will not require specific navigation failure simulations.

2.4.2.6 The number and extent of validation methods used and their duration are directly linked to the complexity of the airspace concept and the traffic sample. The greater the number of changes and the greater their safety and operational impact, the greater the requirement for accurate and detailed investigation to prove the operational benefits and the fulfilment of safety criteria.

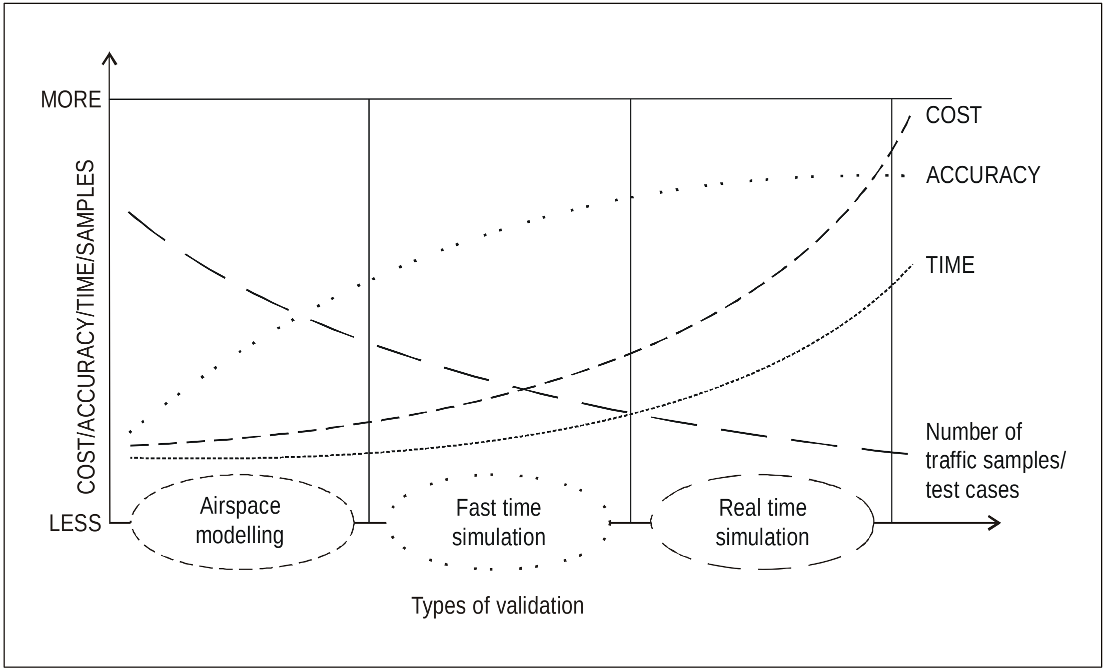

Figure 2-17. Complexity trade-off against cost

2.4.2.7 The design team should allocate enough time in the project plan for the appropriate level of assessment (modelling, FTS and RTS, live trials). The planning should be made as flexible as possible because the results of one validation method could heavily impact upon the next validation step in the sequence or could lead to the suspension of the validation process and a return to the design phase. The validation programme should be carefully mapped out during the project planning phase, and access time to FTS and RTS should be booked well in advance. Many projects have been delayed because of the non-availability of simulators at the crucial time.

2.4.2.8 If issues are identified during the validation requiring a return to the design phase of the project, this should not be resisted. For many reasons, not the least of which is cost, it is better to return to the drawing board sooner rather than later.

2.4.2.9 *Airspace modelling*

2.4.2.9.1 Airspace modelling is computer-based and tends to be one of several validation methods used to validate an airspace design. It is used during the airspace design phase because it enables the airspace design team to visualize, in three dimensions, the placement and profile of routes, the airspace structures and the sectorization.

2.4.2.9.2 Airspace modelling tools can be used as simple, scaled-down, fast time simulators. Their main usage is to create a crude representation of the routes and airspace structures (sectors) together and their interaction with a selected traffic sample. The tool generates simplified 4D trajectories (position + time) according to the flight plans described in the traffic sample (with its rules) in a particular airspace organization (with its rules). These trajectories are used together with the airspace blocks to calculate a series of statistical data such as sector loading, route segment loading and conflicts. More advanced airspace modelling tools can derive more refined data with regard to the workload and sector capacity. The advantages and disadvantages of airspace modelling are listed in Table 2-4.

Table 2-4. Advantages and disadvantages of airspace modelling

Advantages	*Disadvantages*
• flexible • simple to assess various alternatives • easy scenario adaptation • easy generation of test cases • easy to create and assess "what if" tests • easy to test a large number of traffic samples • can use data derived from real traffic and ATC environment	• crude representation of real environment • only provides high-level statistical data • cannot replicate tactical controller interventions • basic aircraft performance • simplified trajectories • no representation of meteorological conditions • accuracy depends heavily on the assessor's ability and experience • high degree of subjectivity, therefore difficult to involve users

2.4.2.10 *FTS*

2.4.2.10.1 FTS is often used to validate a proposed airspace concept, and it may also be used to demonstrate that the safety objectives have been met.

2.4.2.10.2 The airspace design team may use FTS prior to RTS as the only validation tool. FTS is less demanding than RTS in terms of human resources and is often a preferred method for improving a proposed design, identifying flaws in a design concept and/or preparing the path to RTS or direct implementation.

2.4.2.10.3 The airspace organization and traffic sample need to be coded up for the simulated environment using a language and syntax specific to the software. The input data includes routes, the traffic sample assigned to each route, airspace structure and sector, and various rules for aircraft and ATM behaviour.

2.4.2.10.4 The FTS simulator engine generates 4D trajectories (position + time) for each aircraft based upon flight plan information and the rules. The system checks each trajectory for certain predefined events such as conflicts, level changes, route changes, sector entry or exit. When such an event is detected, the system increments a counter and triggers task parameters linked to the event. For example, if the system detects that an aircraft has crossed a sector border, it will increase by one the number of aircraft counted in that specific sector and will trigger as active the tasks assigned to the controllers (such as hand-over, transfer of communication, identification). In the simulator model, controller actions are described by task. These tasks are basic ATC actions, which are triggered by specific events and have a time value associated with it. This value is the time required in real life for the controller to fulfil the specific action. The simulator adds the values of the task parameter for a given test case, and the result gives an indication of controller workload. Usually, a controller is considered not to be overloaded if this figure does not exceed 70 per cent of the total time of the test case. The precision of workload measurement improves when the ATC modus operandi is more detailed and formalized. The advantages and disadvantages of FTS are listed in Table 2-5.

2.4.2.11 *RTS*

2.4.2.11.1 RTS is used in the later stages of the validation of a proposed airspace design and may also be used as a way of demonstrating that both the safety objectives and operational objectives have been met. RTS is often used as a final check and preparatory step towards implementation. This method is used mainly because it provides live feedback from the operational air traffic controllers and for its potential for a high degree of realism. RTS also allows air traffic controllers to become familiar with proposed changes.

2.4.2.11.2 RTS tries to replicate the real working environment of air traffic controllers as accurately as possible. The main components of an RTS platform are:

a) simulator engine;

b) active controller positions;

c) pseudo pilots and feeder sectors; and

d) data recording system.

2.4.2.11.3 The simulator engine processes the flight plans and the inputs from the pseudo pilots and controllers and provides all the active controller positions with the relevant data in the same way as the operational radar data processor) (RDP) and (flight data processor(FDP) systems. The advantages and disadvantages of RTS are listed in Table 2-6 .

Table 2-5. Advantages and disadvantages of FTS

Advantages	*Disadvantages*
• one of the most frequently used methods for sector capacity assessments • opportunity to collect quality data • relatively unlimited scope and great flexibility • relatively simple to assess various alternatives • relatively easy test case adaptation • relatively easy to test large number of traffic samples • can use real traffic and environment data • good acceptance of the results • can evaluate the achievement of the target level of safety (TLS) • can inform safety case development	• simplified model of “real” operation • only provides statistical data • cannot replicate tactical controller interventions • quality of results depends heavily on the accuracy of the model • limited aircraft performance and simplified aircraft behaviour • low representation of meteorological conditions • difficult to involve users

Table 2-6. Advantages and disadvantages of RTS

Advantages	*Disadvantages*
• closest simulation method to the live ATC trials that can be used to assess and validate simulation objectives • gives opportunity to collect high quality quantitative and qualitative data • feedback from controllers, based on operational experience (further qualitative assessment) • feedback from pseudo-pilots (depending on their expertise and simulation conditions) • can indicate and assess Human Factors performance-related issues (further qualitative and quantitative assessment)	• sterile environment: limited human-machine interface (HMI) capabilities, artificial radio transmission (RT), limited radar performance • limited aircraft performance and simplified aircraft behaviour • not realistic aircraft behaviour due to pseudo-pilots without, or with limited, aviation experience • pseudo-pilots cannot replicate real crews’ performance • low representation of meteorological conditions

Advantages	*Disadvantages*
• automatic data collection (for quantitative assessment) • unlimited scope and greater flexibility compared to the live trials (further qualitative assessment) • no risk to the live operation • allows testing of contingency procedures and hazard analysis (qualitative and quantitative assessment) • simple to assess various alternatives • on-line feedback and scenario adaptation (qualitative assessment) • can use real traffic and environmental data (quantitative input) • good acceptance of the results by the controllers (wide scope qualitative assessment) • allows controllers to become familiar with the proposed changes • can be part of a safety case	• Human Factors performance-related issues: – controller mindset/attitude – controller capability – exercise/scenario learning curve – subjectivity of assessment (mainly with regard to workload) – macho attitude – controller's feedback clouded by historic experience • cost and time demanding • potentially resource intensive • scheduling difficulties related to the operational controllers' availability for simulation • difficult to involve users directly

2.4.2.12 *Live ATC trials*

2.4.2.12.1 Live ATC trials are probably the least used validation method. Generally this is because it is perceived as carrying the highest risks despite providing what is probably the highest degree of realism. When used, live trials tend to be aimed at assessing a very specific element of the airspace change such as a new SID or STAR or a new sector design with a very limited traffic sample. The advantages and disadvantages of live ATC trials are listed in Table 2-7.

Table 2-7. Advantages and disadvantages of live ATC trials

Advantages	*Disadvantages*
• the most accurate validation method • real data are collected • gathers feedback from all users • good acceptance of the results by the users	• safety/risk considerations • very detailed post-trial analysis required • limited scope • limited flexibility

2.4.2.13 *Flight simulation*

2.4.2.13.1 Full flight simulators are renowned for their superior realism and accuracy in reproducing all of the operational characteristics of a specific aircraft type. Normal and abnormal situations, including all of the environmental conditions encountered in actual flight, can be precisely simulated. The use of simulators has increased due to advances in technology and the significant cost savings provided by flight simulation training, compared with real flight time. Today's commercial flight simulators are so sophisticated that pilots proficient on one aircraft type can be completely trained in the simulator for a new type before ever flying the aircraft itself.

2.4.2.13.2 In addition to pilot training, flight simulation has an invaluable role to play in other aeronautical areas, such as research, accident investigation, aircraft design and development, operational analysis and other activities such as space flight. Research areas include new concepts, new systems, flying qualities and Human Factors. Most aircraft manufacturers use research simulators as an integral part of aircraft design, development and clearance. Major aeronautical projects would now be impractical without the extensive use of flight simulation, on both cost and safety grounds.

2.4.2.13.3 There are several areas in which a flight simulator can assist in the successful completion of a terminal airspace project. Environmental issues and strong lobby groups are now influencing the positioning of terminal routes (and their associated altitudes) at an increasing number of locations. It can be very difficult, solely by the use of mathematical models and/or FTS, to convince these groups that their environmental concerns have been addressed fully, whereas the realism of the flight simulator can assist the debate considerably.

2.4.2.13.4 Using representative aircraft (simulators), the various options for airspace can be extensively flown, and the data, such as airframe configuration (which affects the noise produced by the aircraft), fuel burn, track miles flown and altitude, recorded. Depending on the requirements of a project and the sophistication of the data gathered, these results can be fed into analysis software for analysis of aircraft noise and emissions.

2.4.2.13.5 The flight simulator is the closest to reality apart from expensive live flight trials, which are difficult to integrate with ongoing operations. The credibility factor is further enhanced if operational line pilots are used to fly the flight simulator. Airlines will be willing to participate by using the new procedures in their simulator to validate the benefits in time and fuel burn.

2.4.2.14 *Noise modelling*

2.4.2.14.1 Political sensitivity to the environmental impact of air transport is a growing concern. The changed placement of any terminal route or the introduction of any new terminal procedure requires an environmental impact assessment in many countries and, very often, the biggest political issue with local councils is aircraft noise.

2.4.2.14.2 Noise models use an advanced form of fast time simulator that is capable of calculating noise contours over a predefined area. These "noise-modelling" functionalities are added to typical functionalities (such as flight trajectory calculation) included in "standard" fast time simulators.

2.4.2.14.3 In order to generate the noise contours for each simulated aircraft in addition to the flight trajectories, the noise modeller determines (according to the aircraft model) the estimated speed and engine power setting/thrust. Based on these data and taking into account the terrain contours and other environmental conditions (time of day, meteorological conditions, etc.), the simulator calculates the noise distribution and noise level at predetermined checkpoints.

2.4.2.14.4 The accuracy of the results very much depends upon the realism of the aircraft models used by the simulator and on the model used for calculating noise distribution. Aircraft trajectories can be directly derived from recorded radar data from live operations, but thrust settings and aircraft configuration have to be modelled. It is difficult to model individual aircraft even when using advanced computational technologies. Movements are allocated to different aircraft "types", and aircraft that are noise "significant" (by virtue of their numbers or noise level) are represented individually by aircraft type, e.g. B747-400. Some types are grouped together with those having similar noise characteristics. For each type, average profiles of height and speed against track distance are calculated from an analysis of radar data and are subdivided into appropriate linear segments.

2.4.2.14.5 Average ground tracks for each route are calculated based on radar data or nominal tracks. Accurate noise exposure estimation requires a realistic simulation of the lateral scatter of flight tracks actually observed in practice. This is done by creating additional tracks which are a number of standard deviations either side of the nominal track. The standard deviations and the proportions of traffic allocated to each route are determined by analysis of the radar data.

2.4.2.14.6 Results from noise models may be used to assist in developing designs that minimize noise impacts. For example, multiple procedures, each tailored to specific aircraft performance levels, may be designed to reduce or distribute noise (see Figure 2-18).

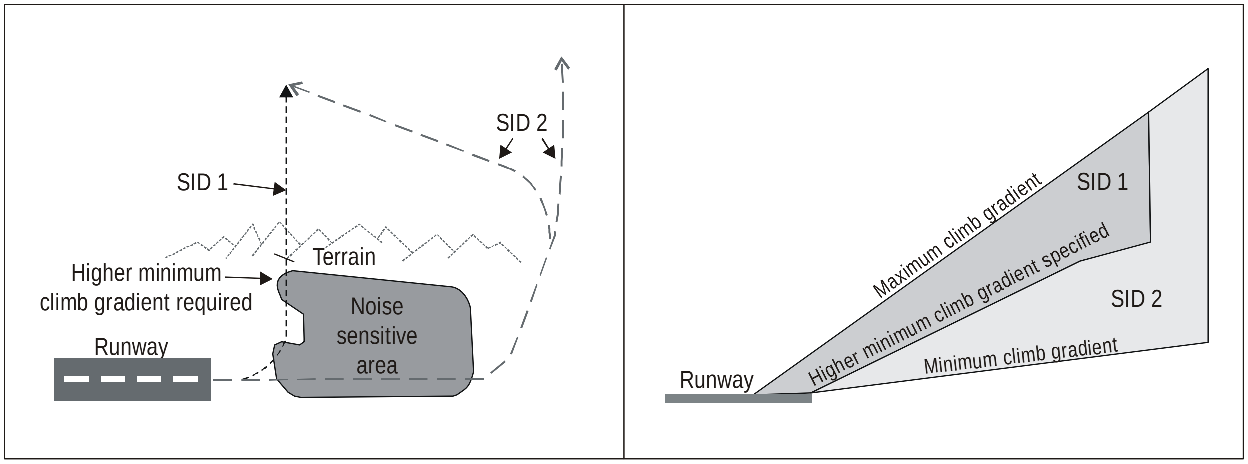

Figure 2-18. Example of noise and performance options

2.4.3 Activity 12: Finalization of procedure design

The procedure design process is only finalized once the airspace concept has been validated. This is because it would be too costly to commence this process without knowing that the proposed concept is viable. Finalization of the design process is achieved when the design documentation is completed, procedure descriptions and draft charts are produced, and each procedure is independently checked to ensure that the design criteria have all been followed.

2.4.4 Activity 13: Validation of procedure design

2.4.4.1 The creation of an RNAV or RNP instrument flight procedure or ATS route follows a series of steps from the origination of aeronautical and obstacle data through survey to the procedure's final publication and its subsequent coding for use in an airborne navigation database. At each step of this process there should be quality control procedures in place to ensure that the necessary levels of accuracy and integrity are achieved and maintained. The quality control procedures for instrument flight procedure design are detailed in Doc 8168 and in Doc 9906, Volume 1 — *Flight Procedure Design Quality Assurance System*. These documents include design reviews by independent designers, desktop software tools to check procedure coding and flyability, flight simulators and flight trials to check flyability, and data comparison exercises to validate coding by the navigation data houses.

2.4.4.2 Initial flyability checks should consider the use of the procedure by a range of aircraft types and in different weather conditions (wind/temperature, etc.). In some cases it may be necessary to employ more specialized software or full flight simulators. Flyability tests using actual aircraft can be considered, but these can only show that a particular aircraft can execute the procedure correctly under a particular set of weather conditions. The size and speed of the aircraft that are available for such flights are seldom representative of the performance of a fully loaded Cat D aircraft.

2.4.4.3 Software tools that use digital terrain data are available to confirm appropriate theoretical navaid coverage. Flight inspection of navaid coverage is only applicable to DME/DME positioning. It requires specially equipped flight inspection aircraft and is extremely time-consuming. In many cases it is possible to establish that the coverage is adequate by use of the software analysis tools and the existing flight inspection reports for the individual navaids.

2.5 IMPLEMENTATION PHASE

2.5.1 The go/no-go decision

2.5.1.1 It is usually during the various validation processes described previously in section 2.4.2 that it becomes evident whether or not the proposed airspace concept is feasible and can be implemented. However, the final decision as to whether to go ahead with implementation needs to be made at a predetermined point in the life cycle of a project.

2.5.1.2 The decision to go ahead with implementation will be based on certain deciding factors as follows:

a) the ATS route/procedure design meets air traffic and flight operations' needs;

b) the safety and navigation performance requirements have been satisfied;

c) the changes to flight plan processing, automation, AIP publications needed to support the implementation have been completed; and

d) the pilot and controller training requirements have been met.

2.5.2 Activity 14: ATC system integration

2.5.2.1 The new airspace concept may require changes to the ATC system interfaces and displays to ensure that controllers have the necessary information on aircraft capabilities and the appropriate displays to support the new routings. The need for such changes would be identified by the design team during the design phase. Such system changes could include modifications to:

a) the air traffic FDP;

b) the air traffic radar data processor (RDP);

c) the ATC situation display; and

d) ATC support tools.

2.5.2.2 There may also be a requirement for changes to air navigation service provider (ANSP) methods for issuing NOTAMS, for example, to support RAIM prediction or to notify the unavailability of specific procedures in the event of a ground NAVAID outage.

2.5.2.3 ATC procedures will also have to be reviewed. The methods by which PBN air traffic is managed can be very different from existing methods, and this will mean that new procedures will have to be developed, trialled and documented. If the PBN implementation involves ATC managing a mixed environment of PBN and non-PBN traffic, this can have a significant impact on the ATC workload and may require major changes to the existing ATC system and procedures. In particular, ATC must be capable of differentiating between capable and non-capable aircraft to ensure that each is accorded the appropriate service and separation.

2.5.2.4 The project team needs to plan for execution of the implementation, not only as regards the local airspace and ANSP, but also in cooperation with any affected parties, which may include ANSPs in an adjacent State.

2.5.3 Activity 15: Awareness and training material

The introduction of PBN can involve considerable investment in terms of training, education and awareness material for both flight crew and controllers. In many States, training packages and computer-based training have been effectively used for some aspects of education and training. ICAO provides additional training material and seminars. Each navigation specification in the PBN manual (Doc 9613), Volume II, Parts B and C, addresses the education and training appropriate for flight crew and controllers.

2.5.4 Activity 16: Implementation

2.5.4.1 Implementation can only be successful through comprehensive implementation planning, as part of the overall project planning, and a very careful review of all critical factors during the planning stage. Moreover, every assumption must be fully justified and carefully planned to make successful implementation possible. This applies to all stages of airspace concept development, validation and implementation.

2.5.4.2 Each ANSP should maintain a standard implementation planning process. Figure 2-19 shows a sample implementation planning process.

2.5.4.3 The decision to go ahead with implementation needs to be made at a particular time in the life cycle of a project and should be based on certain deciding factors, known as implementation criteria, which may include answering the following questions:

a) Have the safety and performance criteria been satisfied?

b) Have the required changes been made to the ATM system?

c) Have the required changes been made to the ground navigation systems?

d) Do the assumptions and conditions upon which the airspace concept has been developed still pertain? (Are traffic flows as forecast? Is the fleet suitably equipped and approved? etc.);

e) Are the critical enablers all in place?

f) Have the pilots and controllers received appropriate training? and

g) Is the business case positive?

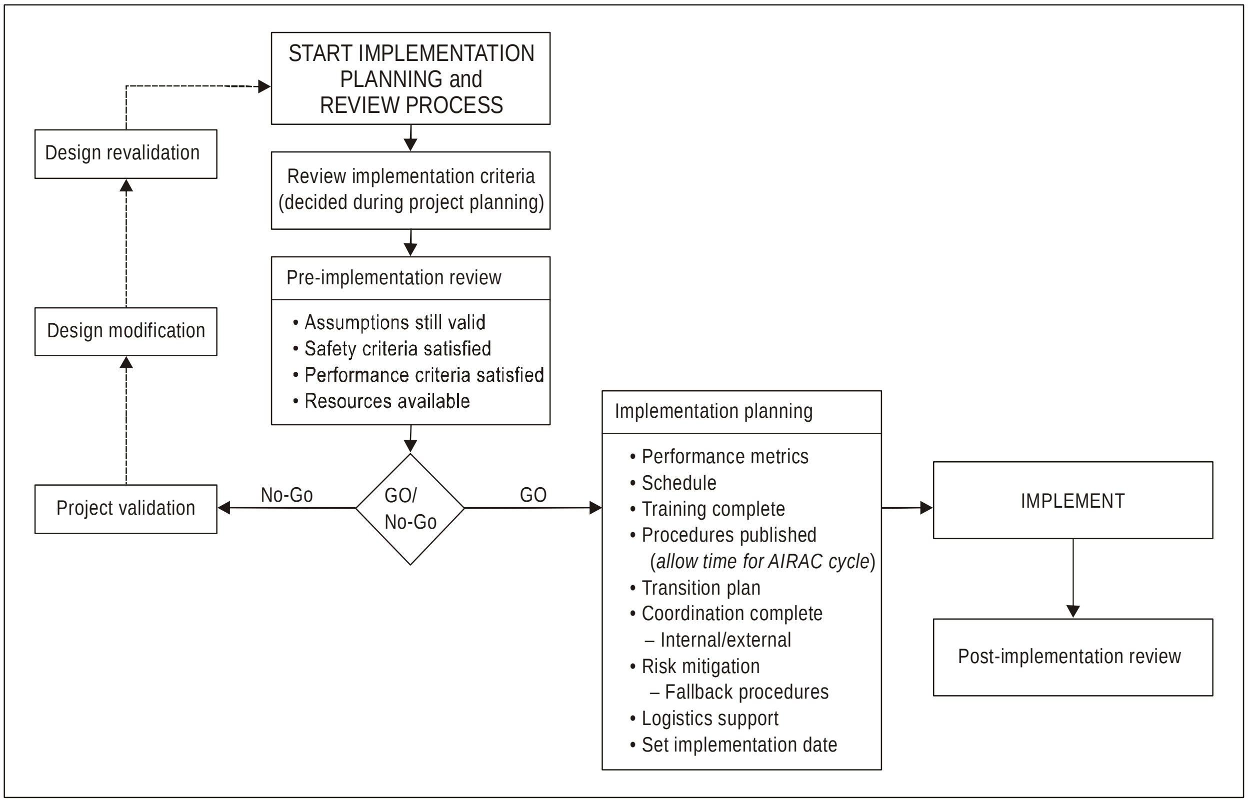

Figure 2-19. Sample implementation planning process

2.5.4.4 It should be noted that unexpected events that are not directly connected with the airspace concept may affect the go/no-go date.

2.5.4.5 A “no-go” decision must be respected. It can be very discouraging, but it is important not to look for “work-arounds” or “quick fixes”. Suggestions that implementation take place at any cost should be strongly resisted.

2.5.4.6 The steps to be followed after a “no-go” decision depend upon the reason for that decision. In extreme cases, it may be necessary to cancel the project and return to the initial planning stage. In other cases, it may be appropriate to review the assumptions, constraints and enablers, or develop a new set of validation exercises or carry out a new safety assessment.

2.5.4.7 Once the “go” decision has been made, the State must establish an effective implementation date taking due account of the data processes and the AIRAC cycle. In order to ensure trouble-free implementation, the airspace design team should remain in close contact with the operational staff. If resources allow, team members should be available in the operations hall on a full-time basis from at least two days before implementation until at least one week after the implementation date. This allows the airspace team to:

a) monitor the implementation process;

b) support the centre supervisor/approach chief or operational manager should it become necessary to use redundancy or contingency procedures;

c) provide support and information to operational controllers and pilots; and

d) maintain a record of implementation-related difficulties for use in future project planning.

2.5.5 Activity 17: Post-implementation review

2.5.5.1 After implementation of the airspace changes, the system should be monitored and operational data collected to ensure that safety is maintained and to determine whether strategic objectives have been achieved. If after implementation, unforeseen events occur, the project team should put mitigation measures in place as soon as possible. In exceptional circumstances, this could require the withdrawal of RNAV or RNP operations while specific problems are addressed.

2.5.5.2 A system safety assessment should be conducted after implementation and evidence collected to ensure that the safety of the system is assured.

— END —

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