ICAO

Cir 341-AN/184

Guidelines for the Implementation of Lateral Separation Minima

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

ICAO

Cir 341-AN/184

Guidelines for the Implementation of Lateral Separation Minima

Approved by and published under the authority of the Secretary General

INTERNATIONAL CIVIL AVIATION ORGANIZATION

Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 Robert-Bourassa Boulevard, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

Cir 341, *Guidelines for the Implementation of Lateral Separation Minima*
Order Number: CIR 341
ISBN 978-92-9249-832-0

TABLE OF CONTENTS

Page

ABBREVIATIONS

A/C	Aircraft
AIC	Aeronautical information circular
AIP	Aeronautical information publication
AIRAC	Aeronautical information regulation and control
AIS	Aeronautical information service
ANSP	Air navigation service provider
ATC	Air traffic control
ATS	Air traffic services
CDI	Course deviation indicator
DCPC	Direct controller-pilot communications
DDE	Double-double-exponential
DME	Distance measuring equipment
DR	Dead reckoning
FAA	Federal Aviation Administration
FD	Fault detection
FDE	Fault detection and exclusion
FL	Flight level
FMS	Flight management system
FPL	Filed flight plan
GLONASS	GLObal NAvigation Satellite System
GNSS	Global navigation satellite system
GPS	Global positioning system
HPL	Horizontal protection limit
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
INS	Inertial navigation system
m	Metre
NDB	Non-directional radio beacon
NDE	Normal-double-exponential
NM	Nautical mile
NOPAC	North pacific
PANS-ATM	Procedures for Air Navigation Services — Air Traffic Management
RAIM	Receiver autonomous integrity monitoring
PBN	Performance-based navigation
RCP	Required communication performance
RGCSP	Review of the General Concept of Separation Panel
RLS	Reference level of safety
RNAV	Area navigation
RNP	Required navigation performance
RSP	Required surveillance performance
SASP	Separation and Airspace Safety Panel
SBAS	Satellite-based augmentation system
TSO	Technical standard order

VHF	Very high frequency
VOR	Very high frequency omnidirectional radio range
WGS-84	World Geodetic System — 1984
WP	Working paper

Chapter 1

INTRODUCTION

1.1 PURPOSE

1.1.1 This circular provides guidance for the implementation of lateral separation minima intended for the separation of aircraft approved for performance-based navigation (PBN) and/or global navigation satellite system (GNSS) operations. It applies to lateral separation of aircraft on intersecting and non-intersecting tracks. The material supports provisions included in Chapter 5 of the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444), 5.4.1.2.1.6 and 5.4.1.2.1.7 — see also Chapter 2 of this circular.

1.1.2 Implementation guidance is also provided in the *Performance-based Navigation (PBN) Manual* (Doc 9613). The manual identifies the relationship between area navigation (RNAV) and required navigation performance (RNP) applications and the advantages and limitations of choosing one or the other as the navigation specification requirement for an airspace concept. The manual also aims at providing practical guidance to States, air navigation service providers and airspace users on how to implement RNAV and RNP applications, and how to ensure that the performance requirements are appropriate for the planned application.

Note.— Guidance for the implementation of lateral separation minima in terminal airspace is provided in ICAO Circular 324 — Guidelines for Lateral Separation of Arriving and Departing Aircraft on Published Adjacent Instrument Flight Procedures*.*

1.1.3 The Separation and Airspace Safety Panel (SASP) developed the separation minima detailed in this circular in response to the ICAO policy on global implementation of PBN, the large number of aircraft equipped with instrument flight rules (IFR) GNSS systems and the potential for using such equipment for separation of aircraft in a procedural environment.

1.1.4 Two of the separation minima covered in this document under the PBN umbrella were originally developed by the Review of the General Concept of Separation Panel (RGCSP) in the 1990s for use within the RNP concept. The first minimum developed was the 93 km (50 NM) lateral separation minimum for RNP followed by the 30 NM lateral separation minimum for RNP 4. Both minima were initially published in *Annex 11 — Air Traffic Services*, but were transferred from Annex 11 to the PANS-ATM at a later date. Improved modelling of RNP subsequently indicated that the 30 NM separation minimum could be reduced to 42.6 km (23 NM) if gross error rates could be sufficiently limited. The SASP found that achieving the prescribed limits was contingent on the application of Required communication performance 240 (RCP 240) and Required Surveillance Performance 180 (RSP 180).

1.1.5 During the transition to full implementation of PBN, there will be a need to provide separation minima based on IFR GNSS systems in aircraft that have yet to obtain appropriate PBN operational approvals. To accommodate the widespread availability of such systems, which provide highly accurate navigation capability, the SASP has developed separation minima that may be applied to aircraft indicating GNSS equipage in the filed flight plan (FPL).

1.2 GENERAL

1.2.1 The continuing growth of aviation increases demands on airspace capacity therefore emphasizing the need for optimum utilization of available airspace. Improved operational efficiency derived from the application of area navigation techniques has resulted in the development of navigation applications in various regions worldwide and for all phases of flight.

1.2.2 Area navigation systems evolved in a manner similar to conventional ground-based routes and procedures. A specific area navigation system was identified and its performance was evaluated through a combination of analysis and flight testing. For domestic operations, the initial systems used very high frequency omnidirectional radio range (VOR) and distance measuring equipment (DME) for estimating aircraft position; for oceanic operations, inertial navigation systems (INS) were employed. Currently, performance-based navigation, as detailed in the PBN manual, introduces alternative methods for defining equipage requirements by specifying the performance requirements.

1.2.3 Requirements for navigation applications on specific routes or within a specific airspace must be defined in a clear and concise manner. This is to ensure that the flight crew and the air traffic controllers (ATCOs) are aware of the on-board RNAV system capabilities in order to determine if the performance of the RNAV system is appropriate for the specific airspace requirements and the applicable separation minima.

1.3 SCOPE

This circular is limited to the application of lateral separation of aircraft operating on intersecting or non-intersecting tracks in a procedural control environment applying area navigation.

Chapter 2

LATERAL SEPARATION MINIMA

2.1 This circular addresses the implementation of the following lateral separation minima published in PANS-ATM, 5.4.1.2.1.6 to 5.4.1.2.1.8 (reproduced here below).

2.2 For intersecting tracks or ATS routes as described in the PANS-ATM, 5.4.1.2.1.7, smaller separations are possible for both RNP 2 and RNP 4 if a restriction is made to the intersection angle. However, applications also exist for angles less than 5 degrees or greater than 175 degrees and the current minimum provides the maximum benefit and also remains consistent with the existing RNP 4, 42.6 km (23 NM) lateral separation minimum that applies on parallel or non-intersecting tracks.

EXTRACT FROM THE PANS-ATM

5.4.1.2 LATERAL SEPARATION CRITERIA AND MINIMA

…

5.4.1.2.1.6 *Lateral separation of aircraft on parallel or non-intersecting tracks or ATS routes.* Within designated airspace or on designated routes, lateral separation between aircraft operating on parallel or non-intersecting tracks or ATS routes shall be established in accordance with the following:

a) for a minimum spacing between tracks of 93 km (50 NM) a navigational performance of RNAV 10 (RNP 10), RNP 4 or RNP 2 shall be prescribed;

b) for a minimum spacing between tracks of 42.6 km (23 NM) a navigational performance of RNP 4 or RNP 2 shall be prescribed. The communication system shall satisfy Required Communication Performance 240 (RCP 240) and the surveillance system shall satisfy Required Surveillance Performance 180 (RSP 180). Conformance monitoring shall be ensured by establishing an ADS-C event contract with a lateral deviation change event with a maximum of 5 NM threshold and a waypoint change event;

c) for a minimum spacing between tracks of 27.8 km (15 NM) a navigational performance of RNP 2 or a GNSS shall be prescribed. Direct controller-pilot VHF voice communication shall be maintained while such separation is applied;

d) for a minimum spacing between tracks of 13 km (7 NM), applied while one aircraft climbs/descends through the level of another aircraft, a navigational performance of RNP 2 or a GNSS equipage shall be prescribed. Direct controller-pilot VHF voice communication shall be maintained while such separation is applied; and

e) for a minimum spacing between tracks of 37 km (20 NM), applied while one aircraft climbs/descends through the level of another aircraft whilst using other types of communication than specified in d) above, a navigational performance of RNP 2 or a GNSS equipage shall be prescribed.

Note 1.— Guidance material for the implementation of the navigation capability supporting 93 km (50 NM), 42.6 km (23 NM), 37 km (20 NM), 27.8 km (15 NM) and 13 km (7 NM) lateral separation minima is contained in the Performance-based Navigation (PBN) Manual *(Doc 9613). Guidance material for the implementation of the 93 km (50 NM), 42.6 km (23 NM), 37 km (20 NM), 27.8 km (15 NM), and 13 km (7 NM) lateral separation minima is contained in Circular 341* — Guidelines for the Implementation of Lateral Separation Minima.

Note 2.— Guidance material for implementation of communication and surveillance capability supporting 42.6 km (23 NM) lateral separation minima is contained in the Performance-based Communication and Surveillance (PBCS) Manual *(Doc 9869, in preparation) and the* Global Operational Data Link (GOLD) Manual *(Doc 10037, in preparation).*

Note 3.— See Appendix 2, Item 10: Equipment and capabilities, in relation to the GNSS prescribed in c), d) and e) above.

5.4.1.2.1.7 *Lateral separation of aircraft on intersecting tracks or ATS routes.* Lateral separation between aircraft operating on intersecting tracks or ATS routes shall be established in accordance with the following.

a) an aircraft converging with the track of another aircraft is laterally separated until it reaches a lateral separation point that is located a specified distance measured perpendicularly from the track of the other aircraft (see Figure 5-6); and

b) an aircraft diverging from the track of another aircraft is laterally separated after passing a lateral separation point that is located a specified distance measured perpendicularly from the track of the other aircraft (see Figure 5-6).

This type of separation may be used for tracks that intersect at any angles using the values for lateral separation points specified below:

Navigation	*Separation (L)*
RNAV 10 (RNP 10)	93 km (50 NM)
RNP 4	42.6 km (23 NM)
RNP 2 or GNSS	27.8 km (15 NM)

5.4.1.2.1.8 When applying the 27.8 km (15 NM) separation minima specified in the table above, a GNSS, as indicated in the flight plan by the letter G meets the specified navigation performance.

Note 1.— Guidance material for the implementation of the navigation capability supporting 93 km (50 NM), 42.6 km (23 NM), and 27.8 km (15 NM) lateral separation minima is contained in the Performance-based Navigation (PBN) Manual *(Doc 9613)*. *Supporting information for the implementation of the 93 km (50 NM), 42.6 km (23 NM) and 27.8 km (15 NM) lateral separation minima is contained in Circular 341* — Guidelines for the Implementation of Lateral Separation Minima.

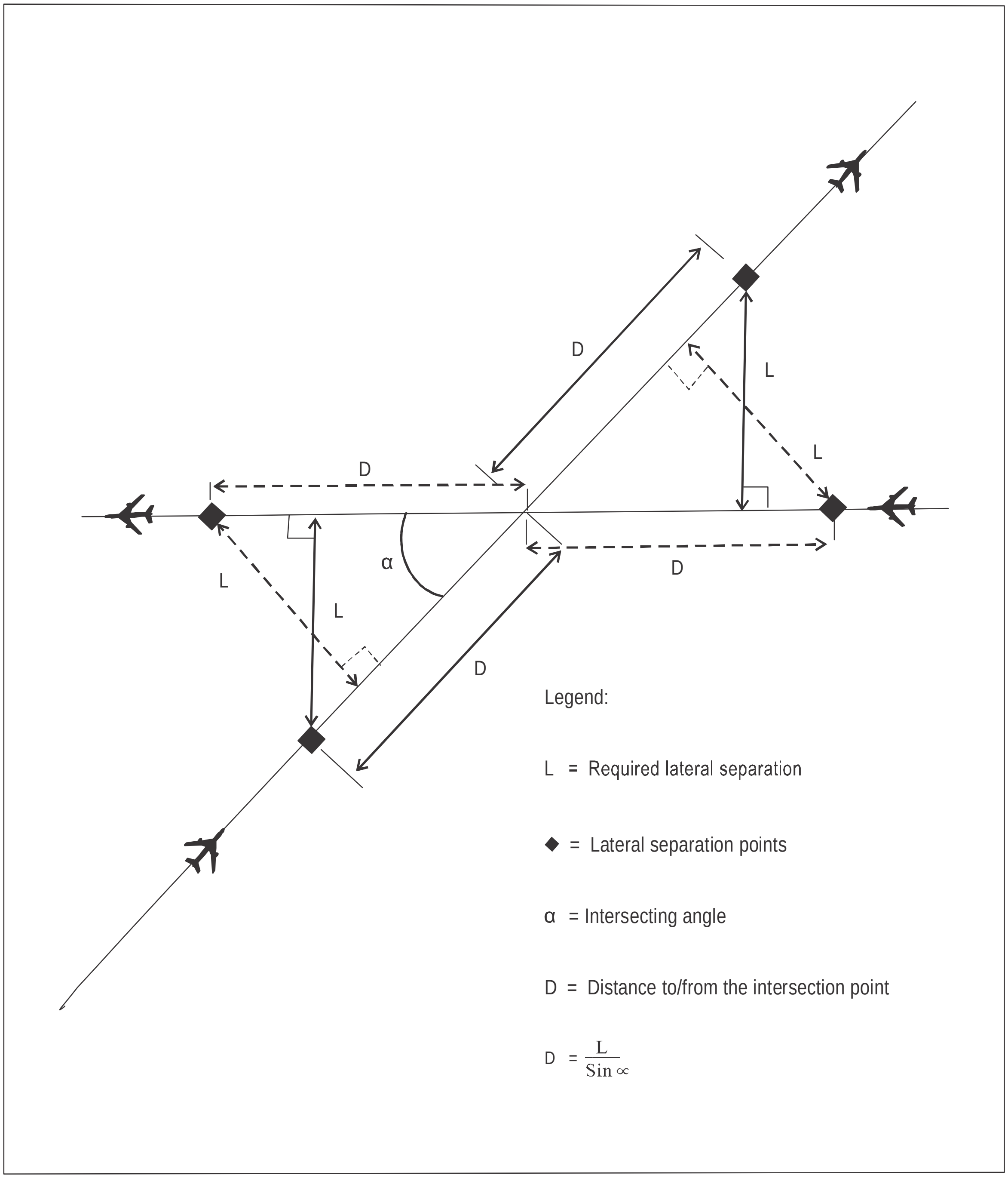

Figure 5-6. Lateral separation points (see 5.4.1.2.1.7)

…

Chapter 3

SASP SAFETY ASSESSMENT

3.1 INTRODUCTION

3.1.1 This chapter summarizes the safety assessments performed by the SASP to determine the lateral separation minima given in the PANS-ATM, 5.4.1.2.1.6 and 5.4.1.2.1.7. This chapter first describes the scope of SASP safety assessments, and then summarizes the method used to arrive at each lateral separation minimum.

3.2 SCOPE OF SASP SAFETY ASSESSMENT

3.2.1 It is useful and necessary to distinguish between safety assessments undertaken by States for the purposes of implementation at the local or regional level and those undertaken by SASP from a *global perspective*. An assessment undertaken for global purposes does not always contain all the information required to address specific local implementation requirements.

3.2.2 The difference in assessment scope is depicted in Figure 3-1. It suggests, for example, that because the local operating environment into which PBN lateral separation is to be integrated may have a significant effect on safety, the full safety assessment can only be completed for each local application. As such, the appropriate ATS authority needs to complement the SASP assessment with an implementation-focussed assessment. It should be noted that a local implementation assessment may not necessarily require a regional assessment but may be initiated by an air navigation service provider (ANSP) on a case-by-case basis.

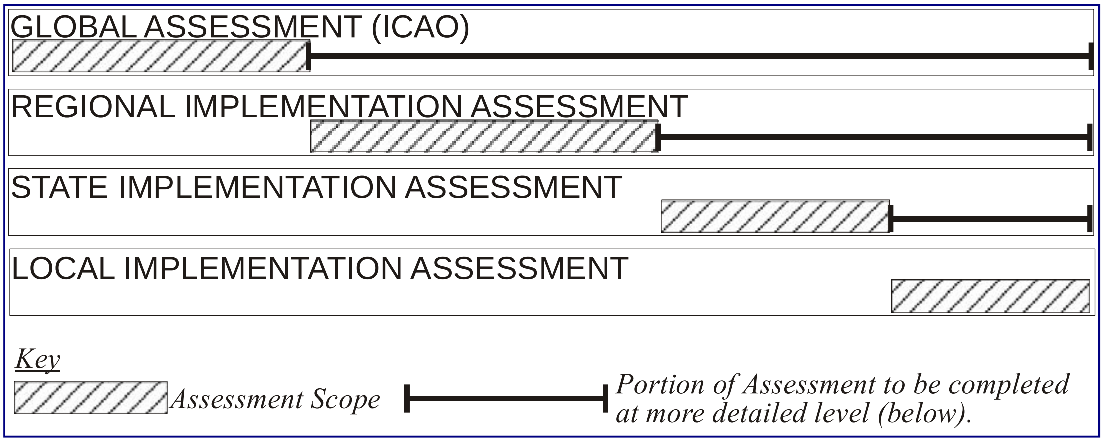

Figure 3-1: Safety assessment scope

3.2.3 SASP's assessment is based on a number of assumed characteristics related to either the airspace environment or aircraft performance (see 3.3.1). These characteristics may not necessarily be the same as those relevant to any particular regional, State or local implementation.

3.2.4 An implementation's supporting safety assessment should begin with a review of the SASP's global assessment, and should take particular note of the assumed characteristics used in that assessment. Where these characteristics are the same as or more stringent than those of the airspace being considered, the analysis only needs to focus on an assessment of matters related specifically to the implementation.

3.3 OBJECTIVES AND DEVELOPMENT OF SASP SAFETY ASSESSMENTS

3.3.1 The objective of the various SASP safety assessments in support of the lateral separation minima referenced in 2.1 of Chapter 2 of this circular was to determine the:

a) minimum safe spacing between parallel tracks for the RNAV 10 (RNP 10), RNP 4, and RNP 2 navigation specifications and also for aircraft equipped with IFR GNSS systems; and

b) minimum safe distance of the lateral separation points on an aircraft's track to the intersecting track of another aircraft for RNAV 10 (RNP 10), RNP 4, and RNP 2 navigation specifications and also for aircraft equipped with IFR GNSS systems.

3.3.2 In assessing the safety of a separation minimum, the SASP distinguishes between collision risk due to navigation performance and risk due to other hazards.

3.3.3 Collision risk due to navigation performance may be subdivided into:

a) collision risk due to typical navigation performance; and

b) collision risk due to atypical navigation performance.

Note.— The expression "atypical navigation performance" may be used to describe lateral deviations due to navigation system failure or degradation, or operational error.

3.3.4 Typical and atypical navigation performance fall within the general framework of hazards, but are special in the sense that they allow a detailed quantitative evaluation. Collision risk due to both types of navigation performance has been quantified by means of collision risk modelling.

3.3.5 The minimum spacing between parallel tracks and the minimum distance of a lateral separation point are considered to be "safe" when the:

a) level of aircraft collision risk (made up of the collision risks due to typical and atypical navigation performance) does not exceed a target level of safety (TLS) of 5×10^{-9} fatal aircraft accidents per flight hour[1]; and

b) risk due to all other hazards is "negligible".

---

[1] A different (but related) unit is used for the climb or decent procedure to be described in section 3.7, viz. a maximum tolerable probability of collision in a typical execution of the procedure of 5×10^{-10}.

3.3.6 The SASP's assessments of collision risk due to navigation performance comply with guidance given in the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689, in preparation) concerning the method of "Evaluation of system risk against a threshold".

3.4 SAFETY ASSESSMENT FOR 93 KM (50 NM) SEPARATION OF NON-INTERSECTING TRACKS — RNAV 10 (RNP 10), RNP 4 OR RNP 2

When implementing the separation specified in this section, the assumptions, enablers, and system performance requirements detailed in the following paragraphs must be taken into account and compared to the characteristics of the airspace where the separation is being implemented. The assumptions and implementation considerations are listed in the table below:

Assumptions	**Implementation considerations**
1. Aircraft cross-track deviations are within 6 NM of the route centre line 95 per cent of the flight time. 2. The rate of lateral deviations larger than 25 NM is less than 1E-5. The occupancy must not exceed 0.2 for opposite-direction traffic. *Note 1.— The value in assumption 2 above may be more stringent than required for some airspaces. Refer to Tables 3.4.1 and 3.4.2 if more detail is desired concerning aggregate navigation performance in the airspace.* *Note 2. — The large lateral deviation (LLD) rate can be expressed as the total time aircraft deviate more than half the separation standard, divided by the total flight hours.* *Note 3. — A route system's "occupancy" is a measure of the risk of collision encountered by an aeroplane that strays from its assigned route toward an adjacent route. Information on computing occupancy is given in the* Manual on Airspace Planning Methodology for the Determination of Separation Minima (*Doc 9689), Appendix 14, Introduction.*	Implementation of a lateral separation standard of 93 km (50 NM) requires appropriate monitoring to ensure the assumptions are met.

Safety assessment for navigation performance

3.4.1 The safety assessment for 93 km (50 NM) spacing of parallel routes for RNAV 10 (RNP 10) capable aircraft was presented in Working Paper 4 of the 17th Meeting of Working Group A of the Review of the General Concept of Separation Panel (RGCSP) (Ref. 1)[2]. It was based on the "Reich model" formulae for the rates of collision due to the loss of planned lateral separation: one for a pair of co-altitude parallel flight paths whose traffic moves in the same direction, the other for a pair of co-altitude parallel flight paths whose traffic moves in opposite directions:

$$N_{ay}(same) = P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}E_y(same)\left\{\frac{\overline{|\Delta V|}}{2\lambda_x}+\frac{\overline{|\dot{y}|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\} \tag{3.4.1}$$

$$N_{ay}(opp) = P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}E_y(opp)\left\{\frac{2\overline{|V|}}{2\lambda_x}+\frac{\overline{|\dot{y}|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right\} \tag{3.4.2}$$

The formulae are nearly identical, differing only in the parameters that are sensitive to the direction of flight. Thus the reasoning behind the assessment is explained once, and then applied with two (slightly) different sets of parameter values.

3.4.3 The route system's estimated rate of accidents due to the loss of planned lateral separation was required not to exceed its maximum tolerable value, the target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour.

3.4.4 In a system whose adjacent routes are laterally separated by 93 km (50 NM), the probability of a lateral deviation whose magnitude is two or more separation standards is considered to be relatively small. A good estimate of lateral risk can be obtained by considering only those deviations that move the errant aeroplane approximately one separation standard away from its intended path in space.

3.4.5 The assessment assumed that aircraft lateral deviations from centre line are well-described by a double-double-exponential (DDE) probability density function with mean zero and parameters α, λ_1, and λ_2, i.e.

$$f(y;\alpha,\lambda_1,\lambda_2) = \frac{1-\alpha}{2\lambda_1}e^{-\frac{|y|}{\lambda_1}} + \frac{\alpha}{2\lambda_2}e^{-\frac{|y|}{\lambda_2}} \tag{3.4.3}$$

This function is a weighted sum of the density function of typical errors and the density function of atypical errors. The parameter λ_1 is $1/\sqrt{2}$ times the standard deviation of typical lateral errors; the parameter λ_2 is $1/\sqrt{2}$ times the standard deviation of atypical lateral errors; $\lambda_2 > \lambda_1 > 0$; and the parameter α ($1 > \alpha > 0$) is the fraction of flying time during which aeroplanes using the route system are committing atypical errors.

---

[2] References are numbered 1, 2, 3, ... by section and are listed at the end of each section.

3.4.6 The lateral overlap probability of aeroplanes assigned to parallel routes, spaced S_y nautical miles apart, can be derived from the DDE density function as $P_y(S_y) \approx$

$$2\lambda_y\left[\left(\frac{1-\alpha}{2\lambda_1}\right)^2(\lambda_1+S_y)e^{-\frac{S_y}{\lambda_1}}+\left(\frac{\alpha}{2\lambda_2}\right)^2(\lambda_2+S_y)e^{-\frac{S_y}{\lambda_2}}+\frac{\alpha(1-\alpha)}{2}\left(\frac{e^{-\frac{S_y}{\lambda_1}}+e^{-\frac{S_y}{\lambda_2}}}{\lambda_1+\lambda_2}+\frac{e^{-\frac{S_y}{\lambda_2}}-e^{-\frac{S_y}{\lambda_1}}}{\lambda_2-\lambda_1}\right)\right]$$

$$\lambda_1 \neq \lambda_2 \qquad (3.4.4)$$

3.4.7 For both same-direction flight and opposite-direction flight the assessment began by deriving the maximum tolerable lateral overlap probability for a pair of randomly chosen aeroplanes, one assigned to each of the co-altitude flight paths. This was done by substituting the maximum tolerable value of 5×10^{-9} fatal accidents per flight hour for $N_{ay}(same)$ and $N_{ay}(opp)$ in the left sides of equations (3.4.1) and (3.4.2), substituting suitable values for all parameters other than $P_y(S_y;\alpha,\lambda_1,\lambda_2)$ in the right sides of equations (3.4.1) and (3.4.2), and then solving for $P_y(S_y;\alpha,\lambda_1,\lambda_2)$. The resulting maximum tolerable probabilities, one for same-direction flight and one for opposite-direction flight, were stated as functions of the route system's occupancy; and all calculations were done for occupancies ranging from 0.1 to 2.0, in steps of 0.1.

3.4.8 The next step required the standard deviation of typical errors (equivalently, λ_1) to be kept so small that the lateral overlap probability would be almost entirely due to large atypical errors that move an aeroplane to the vicinity of an adjacent route, where it has a significant probability of being in lateral overlap with an aeroplane assigned to that route. The lateral overlap probability due to large atypical errors was then approximated by a function of λ_2 and α only; and it was shown that, as a function of λ_2, the approximation reached its maximum when λ_2 equalled the spacing S_y between adjacent routes. Setting this maximum value equal to the maximum tolerable lateral overlap probability then yielded a solution for the minimal (most conservative) value of α.

3.4.9 Having assumed a conservative value for λ_2, and having derived a conservative value for α, the assessment returned to λ_1 by finding a maximum tolerable value for it. To this end, the lateral overlap probability due to typical errors was approximated and required to be less than or equal to 1 per cent of the (approximation to the) lateral overlap probability due to atypical errors. It was then shown that the only way to decrease the lateral overlap probability due to typical errors was to decrease λ_1; and the largest value of λ_1 was found which satisfied the 1 per cent requirement.

3.4.10 With the above process, all three parameters, α, λ_1, and λ_2, of the density function of lateral errors, were determined such that the TLS would not be exceeded and the risk due to typical errors would be less than or equal to 1 per cent of the (approximation to the) risk due to atypical errors.

3.4.11 The final step was to translate the probability density function parameter λ_1 into a performance requirement. This was achieved by multiplying the theoretic value of λ_1 (cf. 3.4.9) by the constant $-\ln(0.05)$ (which is approximately equal to 3) to obtain the 95 per cent containment distance for typical lateral errors. Rounding that number to the next lower integer gave the RNP value that should be imposed on users of the route system (dividing this RNP value by $-\ln(0.05)$ then gave the effective value of λ_1).

3.4.12 The assessment found that at most levels of lateral occupancy, same-direction route systems would need to impose RNP 7 in order to meet the TLS, and opposite-direction route systems would need to impose RNP 6 in order to meet the TLS. However, the RGCSP and its successor, the SASP, both declined to consider the development of standards for either RNP 7 or RNP 6.

3.4.13 In a note dealing with the history of 93 km (50 NM) route spacing, reference 1 observed that an earlier RGCSP study, using a less stringent TLS of 2×10^{-8} fatal accidents per flight hour, had derived a 95 per cent containment distance of 8 NM for typical lateral errors (Ref. 4). The study pertained to the North Pacific (NOPAC) route system and used occupancy values extrapolated to the year 1995. However, the authorities responsible for flights on the NOPAC route system imposed a less demanding containment distance of 10 NM, i.e. RNP 10. It had been suggested that they did so because of concerns as to the ability of the NOPAC fleet to satisfy RNP 8. It was also suggested that some aeroplanes that were nominally “RNP 10” were likely to navigate with 95 per cent containment distances far smaller than 8 NM, thereby producing a “fleet average” performance that would meet the 8 NM requirement.

3.4.14 As a part of the safety assessment, formulae were also provided for two additional parameters that are more easily observed by air navigation service providers than are the parameters λ_2 and α: the rate of gross lateral errors, usually called η, and the rate of high-risk gross lateral errors, usually called ζ. A gross lateral error is a lateral error that exceeds half the separation standard (i.e. for 93 km (50 NM) separation, an error whose magnitude exceeds 25 NM); and a route system’s value of η is the fraction of flight time that its fleet spends committing gross lateral errors. A high-risk gross lateral error is one that places the errant aeroplane in proximity to an adjacent route. The SASP adopted a proximity criterion of 10 NM, so that high-risk gross lateral errors are those whose magnitudes are between 40 NM and 60 NM. A route system’s value of ζ is the fraction of flight time that its fleet spends committing high-risk gross lateral errors. Using the maximum tolerable values of α and λ_1, and the conservative choice of λ_2, reference 1 derived the maximum tolerable values for η and ζ corresponding to each level of occupancy.

3.4.15 Tables 3.4.1 and 3.4.2 show the calculated maximum tolerable values for the rates of gross lateral errors and high-risk gross lateral errors for same-direction flight and opposite-direction flight respectively. Each table shows the maximum tolerable values for η and ζ as a function of occupancy.

3.4.16 Some additional work related to the safety assessment for 93 km (50 NM) spacing of parallel routes for RNAV 10 (RNP 10) aircraft is documented in references 4 to 11.

Hazard assessment

3.4.17 Refer to section 3.9 and Attachment A for a description of the SASP hazard assessment.

Table 3.4.1 Maximum acceptable values of parameters describing navigational performance, for a system of same-direction parallel routes with 93 km (50 NM) between adjacent routes, for a target level of safety (TLS) of 5 × 10^{-9} fatal accidents per flight hour, for the parameter values given in Table 1 of reference 1, for core-core interaction limited to 1 per cent of core-tail interaction, and for the given values of same-direction occupancy, $E_y(same)$

$E_y(same)$	$P_y(S_y)$	α	theoretic λ_1	RNP	applied λ_1	η	ζ
0.1	$2.33 \cdot 10^{-7}$	$5.11 \cdot 10^{-4}$	2.8528	8	2.67	$3.96 \cdot 10^{-4}$	$7.59 \cdot 10^{-5}$
0.2	$1.16 \cdot 10^{-7}$	$2.55 \cdot 10^{-4}$	2.7312	8	2.67	$2.41 \cdot 10^{-4}$	$3.81 \cdot 10^{-5}$
0.3	$7.76 \cdot 10^{-8}$	$1.70 \cdot 10^{-4}$	2.6651	7	2.34	$1.26 \cdot 10^{-4}$	$2.52 \cdot 10^{-5}$
0.4	$5.82 \cdot 10^{-8}$	$1.28 \cdot 10^{-4}$	2.6202	7	2.34	$1.00 \cdot 10^{-4}$	$1.89 \cdot 10^{-5}$
0.5	$4.66 \cdot 10^{-8}$	$1.02 \cdot 10^{-4}$	2.5864	7	2.34	$8.45 \cdot 10^{-5}$	$1.52 \cdot 10^{-5}$
0.6	$3.88 \cdot 10^{-8}$	$8.51 \cdot 10^{-5}$	2.5595	7	2.34	$7.42 \cdot 10^{-5}$	$1.26 \cdot 10^{-5}$
0.7	$3.33 \cdot 10^{-8}$	$7.29 \cdot 10^{-5}$	2.5372	7	2.34	$6.68 \cdot 10^{-5}$	$1.08 \cdot 10^{-5}$
0.8	$2.91 \cdot 10^{-8}$	$6.38 \cdot 10^{-5}$	2.5182	7	2.34	$6.13 \cdot 10^{-5}$	$9.49 \cdot 10^{-6}$
0.9	$2.59 \cdot 10^{-8}$	$5.67 \cdot 10^{-5}$	2.5017	7	2.34	$5.70 \cdot 10^{-5}$	$8.44 \cdot 10^{-6}$
1.0	$2.33 \cdot 10^{-8}$	$5.11 \cdot 10^{-5}$	2.4871	7	2.34	$5.35 \cdot 10^{-5}$	$7.60 \cdot 10^{-6}$
1.1	$2.12 \cdot 10^{-8}$	$4.64 \cdot 10^{-5}$	2.4741	7	2.34	$5.07 \cdot 10^{-5}$	$6.91 \cdot 10^{-6}$
1.2	$1.94 \cdot 10^{-8}$	$4.25 \cdot 10^{-5}$	2.4624	7	2.34	$4.84 \cdot 10^{-5}$	$6.34 \cdot 10^{-6}$
1.3	$1.79 \cdot 10^{-8}$	$3.93 \cdot 10^{-5}$	2.4516	7	2.34	$4.64 \cdot 10^{-5}$	$5.85 \cdot 10^{-6}$
1.4	$1.66 \cdot 10^{-8}$	$3.65 \cdot 10^{-5}$	2.4418	7	2.34	$4.47 \cdot 10^{-5}$	$5.44 \cdot 10^{-6}$
1.5	$1.55 \cdot 10^{-8}$	$3.40 \cdot 10^{-5}$	2.4327	7	2.34	$4.32 \cdot 10^{-5}$	$5.08 \cdot 10^{-6}$
1.6	$1.46 \cdot 10^{-8}$	$3.19 \cdot 10^{-5}$	2.4243	7	2.34	$4.19 \cdot 10^{-5}$	$4.76 \cdot 10^{-6}$
1.7	$1.37 \cdot 10^{-8}$	$3.00 \cdot 10^{-5}$	2.4164	7	2.34	$4.08 \cdot 10^{-5}$	$4.49 \cdot 10^{-6}$
1.8	$1.29 \cdot 10^{-8}$	$2.84 \cdot 10^{-5}$	2.4091	7	2.34	$3.98 \cdot 10^{-5}$	$4.24 \cdot 10^{-6}$
1.9	$1.23 \cdot 10^{-8}$	$2.69 \cdot 10^{-5}$	2.4021	7	2.34	$3.89 \cdot 10^{-5}$	$4.02 \cdot 10^{-6}$
2.0	$1.16 \cdot 10^{-8}$	$2.55 \cdot 10^{-5}$	2.3956	7	2.34	$3.80 \cdot 10^{-5}$	$3.82 \cdot 10^{-6}$

Table 3.4.2 Maximum acceptable values of parameters describing navigational performance, for a system of parallel flight paths with 93 km (50 NM) between adjacent paths and opposite-direction traffic on adjacent paths, for a target level of safety (TLS) of 5 × 10^{-9} fatal accidents per flight hour, for the parameter values given in Table 1 of reference 1, for core-core interaction limited to 1 per cent of core-tail interaction, and for the given values of opposite-direction occupancy, E_y(opp)

$E_y(opp)$	$P_y(S_y)$	α	theoretic λ_1	RNP	applied λ_1	η	ζ
0.1	$2.29 \cdot 10^{-8}$	$5.01 \cdot 10^{-5}$	2.4846	7	2.34	$5.30 \cdot 10^{-5}$	$7.46 \cdot 10^{-6}$
0.2	$1.14 \cdot 10^{-8}$	$2.51 \cdot 10^{-5}$	2.3932	7	2.34	$3.78 \cdot 10^{-5}$	$3.75 \cdot 10^{-6}$
0.3	$7.62 \cdot 10^{-9}$	$1.67 \cdot 10^{-5}$	2.3430	7	2.34	$3.27 \cdot 10^{-5}$	$2.51 \cdot 10^{-6}$
0.4	$5.71 \cdot 10^{-9}$	$1.25 \cdot 10^{-5}$	2.3087	6	2.00	$1.14 \cdot 10^{-5}$	$1.86 \cdot 10^{-6}$
0.5	$4.57 \cdot 10^{-9}$	$1.00 \cdot 10^{-5}$	2.2828	6	2.00	$9.87 \cdot 10^{-6}$	$1.49 \cdot 10^{-6}$
0.6	$3.81 \cdot 10^{-9}$	$8.35 \cdot 10^{-6}$	2.2621	6	2.00	$8.86 \cdot 10^{-6}$	$1.24 \cdot 10^{-6}$
0.7	$3.27 \cdot 10^{-9}$	$7.16 \cdot 10^{-6}$	2.2449	6	2.00	$8.13 \cdot 10^{-6}$	$1.06 \cdot 10^{-6}$
0.8	$2.86 \cdot 10^{-9}$	$6.26 \cdot 10^{-6}$	2.2302	6	2.00	$7.59 \cdot 10^{-6}$	$9.30 \cdot 10^{-7}$
0.9	$2.54 \cdot 10^{-9}$	$5.57 \cdot 10^{-6}$	2.2174	6	2.00	$7.17 \cdot 10^{-6}$	$8.27 \cdot 10^{-7}$
1.0	$2.29 \cdot 10^{-9}$	$5.01 \cdot 10^{-6}$	2.2061	6	2.00	$6.83 \cdot 10^{-6}$	$7.44 \cdot 10^{-7}$
1.1	$2.08 \cdot 10^{-9}$	$4.55 \cdot 10^{-6}$	2.1958	6	2.00	$6.56 \cdot 10^{-6}$	$6.77 \cdot 10^{-7}$
1.2	$1.90 \cdot 10^{-9}$	$4.18 \cdot 10^{-6}$	2.1867	6	2.00	$6.33 \cdot 10^{-6}$	$6.21 \cdot 10^{-7}$
1.3	$1.76 \cdot 10^{-9}$	$3.85 \cdot 10^{-6}$	2.1784	6	2.00	$6.13 \cdot 10^{-6}$	$5.73 \cdot 10^{-7}$
1.4	$1.63 \cdot 10^{-9}$	$3.58 \cdot 10^{-6}$	2.1707	6	2.00	$5.96 \cdot 10^{-6}$	$5.32 \cdot 10^{-7}$
1.5	$1.52 \cdot 10^{-9}$	$3.34 \cdot 10^{-6}$	2.1636	6	2.00	$5.82 \cdot 10^{-6}$	$4.97 \cdot 10^{-7}$
1.6	$1.43 \cdot 10^{-9}$	$3.13 \cdot 10^{-6}$	2.1570	6	2.00	$5.69 \cdot 10^{-6}$	$4.66 \cdot 10^{-7}$
1.7	$1.34 \cdot 10^{-9}$	$2.95 \cdot 10^{-6}$	2.1509	6	2.00	$5.58 \cdot 10^{-6}$	$4.39 \cdot 10^{-7}$
1.8	$1.27 \cdot 10^{-9}$	$2.78 \cdot 10^{-6}$	2.1451	6	2.00	$5.48 \cdot 10^{-6}$	$4.14 \cdot 10^{-7}$
1.9	$1.20 \cdot 10^{-9}$	$2.64 \cdot 10^{-6}$	2.1397	6	2.00	$5.39 \cdot 10^{-6}$	$3.93 \cdot 10^{-7}$
2.0	$1.14 \cdot 10^{-9}$	$2.51 \cdot 10^{-6}$	2.1346	6	2.00	$5.31 \cdot 10^{-6}$	$3.73 \cdot 10^{-7}$

References:

1. *Navigational Requirements for the Implementation of 50-nm Route Spacing in Oceanic Airspace*, RGCSP-WG/A/17-WP/4, Annapolis, USA, 6 – 17 November 2000.
2. *Air Traffic Services Planning Manual*, First Edition – 1984, Doc 9426-AN/924.
3. *Manual on Airspace Planning Methodology for the Determination of Separation Minima*, First Edition – 1998, Doc 9689-AN/953.
4. *Capabilities of FANS-1/A Aircraft Which Can Lead to Separation Standards Reductions*, RGCSP/WG-A/IP/17, Shizuoka, Japan, 13 – 23 September 1994.
5. *Documenting the rationale supporting 50 NM route spacing in North Pacific airspace*, RGCSP/10-WP/22, Montreal, Canada, 8 to 19 May 2000.
6. *On the Adequacy of Performance Requirements for Route Systems Using 50 NM Lateral Separation*, SASP-WG/A/2-WP/5, Montreal, Canada, 29 October – 9 November 2001.
7. *Some Further Observations on the Adequacy of Performance Requirements for Route Systems Using 50 NM Lateral Separation*, SASP-WG/A/2-WP/25, Montreal, Canada, 29 October – 9 November 2001.
8. *Maximum Acceptable Rates of Gross Lateral Errors for Systems of Parallel Routes with 50-nmi Spacing*, SASP-WG/WHL/5-WP/3, Tokyo, 17 – 28 May 2004.
9. *Amendments to Document 4444, PANS-ATM, to Incorporate Material Formerly Located in Attachment B to Annex 11*, SASP-WG/WHL/13-WP/6, Montreal, Canada, 12 – 23 May 2008.
10. *Status of Current SASP* PANS ATM *Amendment Proposals,* SASP-WG/WHL/16-WP/10, Auckland, New Zealand, 9 – 20 November 2009.
11. *An update on the Status of Certain Amendment Proposals Advanced by SASP Last Year,* SASP-WG/WHL/17-WP/10, Montreal, Canada, 10 – 21 May 2010.

3.5 SAFETY ASSESSMENT FOR 42.6 KM (23 NM) SEPARATION OF NON-INTERSECTING TRACKS USED BY A FLEET WHOSE AIRCRAFT ALL MEET EITHER RNP 4 OR RNP 2

When implementing the separation specified in this section the assumptions, enablers, and system performance requirements detailed in the following paragraphs must be taken into account and compared to the characteristics of the airspace where the separation is being implemented. The assumptions and implementation considerations are listed in the table below:

Assumptions	**Implementation considerations**
1. Aircraft cross-track deviations are within 4 NM of the route centre line 95 per cent of the flight time. 2. The rate of lateral deviations larger than 11.5 NM is less than 1E-6. The occupancy must not exceed 0.2 for opposite-direction traffic. *Note 1. — The value in assumption 2 above may be more stringent than required for some airspaces and less stringent than required when occupancy exceeds 0.2 for opposite-direction traffic. Refer to tables 3.5.1 to 3.5.5. If more detail is required concerning aggregate navigation performance in the airspace.* *Note 2. — The large lateral deviation (LLD) rate can be expressed as the total time aircraft deviate more than half the separation standard, divided by the total flight hours.* *Note 3. — A route system's "occupancy" is a measure of the risk of collision encountered by an aeroplane that strays from its assigned route toward an adjacent route. Information on computing occupancy is given in the* Manual on Airspace Planning Methodology for the Determination of Separation Minima *(Doc 9689), Appendix 14, Introduction.*	Implementation of a lateral separation standard of 42.6 km (23 NM) requires appropriate monitoring to ensure the assumptions are met.

Safety assessment for navigation performance

3.5.1 A paper presented at the November 2013 meeting of the SASP working group of the whole (Ref. 1), suggested minimum tolerable spacing distances for pairs of parallel routes whose traffic is restricted to aeroplanes satisfying given levels of required navigation performance (RNP). Using one of the results of that paper, and assuming a "worst-case" application of strategic lateral offsets, a paper presented to the November 2014 meeting of the working group (Ref. 2) suggested the use of 42.6 km (23 NM) spacing between adjacent parallel routes that carry RNP 4 aeroplanes. A paper presented to the May 2015 meeting of the SASP (Ref. 5) derived maximum tolerable rates of gross lateral errors for several different configurations of parallel routes, when the spacing between the centre lines of adjacent routes is assumed to be 42.6 km (23 NM).

3.5.2 Five route configurations were considered in reference 5. All of the routes were assumed to be unidirectional, in that each of them carries traffic moving in the same direction on all of its flight levels. The five route configurations were:

a) two routes carrying traffic in opposite directions, oriented so that the aeroplanes on each route have those of the other route on their left;

b) two routes carrying traffic in opposite directions, oriented so that the aeroplanes on each route have those of the other route on their right;

c) two routes carrying traffic in the same direction;

d) four routes, all carrying traffic in the same direction, all using the same three flight levels, and having traffic concentrated on the middle routes and middle flight levels;

e) seven routes, all carrying traffic in the same direction, all using the same seven flight levels, and having traffic concentrated on the middle routes and middle flight levels.

3.5.3 Since the SASP did not have any information on the distribution of strategic lateral offsets applied by the fleets that would eventually use the route systems, it conservatively assumed that the intended lateral separation between the flight paths of aeroplanes assigned to adjacent routes, would be as small as allowable. Thus, for opposite-direction routes that are oriented so that the aeroplanes on each route have those of the other route on their left, the SASP assumed that offsets are not applied, and the intended separation would be 42.6 km (23 NM). For opposite-direction routes that are oriented so that the aeroplanes on each route have those of the other route on their right, all aeroplanes were assumed to apply the maximum offset of 2 NM (to the right), so that the intended separation between aeroplanes assigned to adjacent routes would be 19 NM. For same-direction routes (imagined with traffic going away from the viewer), the SASP assumed that aeroplanes on the left would apply the 2-nmi offset, while those on the right would aim to fly along the centre line; and thus the separation between the intended paths would be 21 NM. In the system of four routes, the minimum intended separation for aeroplanes assigned to routes having 46 NM between centre lines, would be 44 NM; and for aeroplanes assigned to routes having 69 NM between centre lines, the minimum intended separation would be 67 NM. The system of seven routes has route pairs whose centre lines are separated by 42.6 km (23 NM), 46 NM, 69 NM, 92 NM, 115 NM and 138 NM; and the minimum intended separations would be, respectively, 21 NM, 44 NM, 67 NM, 90 NM, 113 NM, and 136 NM.

3.5.4 For each of the five route configurations, the SASP applied the Reich model in order to estimate the rate of accidents due to the loss of planned lateral separation. The equations of the Reich model are given above, in the preceding section, as equations (3.4.1) and (3.4.2); but in the work described in that section, they were used to derive maximum tolerable rates of gross errors for route systems having 93 km (50 NM) between adjacent routes, and fleets meeting RNAV 10. This section, on the other hand, describes the SASP's derivation of maximum tolerable rates of gross errors for systems whose adjacent routes have 42.6 km (23 NM) spacing, and whose fleets meet RNP 4. Thus it was necessary to assign different values to some of the parameters used in the Reich models. The values used by the SASP are shown in Figures 1 through 5 of reference 5. The SASP also changed the way it computes lateral overlap probability – the factor called $P_y(S_y)$ in equations (3.4.1) and (3.4.2). The safety assessment summarized in section 3.4 assumed that aeroplanes' lateral deviations from their assigned routes have a double-double-exponential (DDE) distribution. While this assumption is appropriate for RNAV 10 aircraft, in 2006 the SASP adopted the convention that aeroplanes meeting RNP 4 should be assumed to have normally distributed typical deviations, and double-exponentially distributed atypical deviations. Thus it characterized the lateral deviations of RNP 4 aeroplanes as having normal-double-exponential (NDE) densities. An NDE density function is a weighted sum of a normal density and a double-exponential density, both with mean equal to 0. The standard deviation of the normal density was called σ, the parameter of the double-exponential density was called λ, and the weighting factor — i.e. the fraction of flight time in which aeroplanes' deviations are (at least partly) due to atypical causes — was called α. Because ICAO requires aeroplanes meeting RNP 4 to exhibit 95 per cent lateral containment within 4 NM of their intended flight paths, the value of the parameter σ was taken to be the value that provides this level of containment, i.e. $4/1.959964 = 2.0408538...$. The value assigned to λ was the minimum intended lateral separation between aeroplanes assigned to adjacent routes, which (as described above) takes one of the values 42.6 km (23 NM), 19 NM or 21 NM, depending on the route system being considered. Previous studies have shown that taking λ equal to the minimum intended separation provides a very good approximation to its "worst-case" value. The SASP then applied formulas from reference 4 in order to compute the lateral overlap probabilities used in the Reich models. For each of the five route systems, and for each of 20 values of occupancy — ranging from 0.1 to 2.0, in steps of 0.1 — the SASP computed the value of α that yields an accident rate equal to the target level of safety (TLS) of 5×10^{-9} accidents per flight hour. Since the SASP considers this accident rate to be the worst tolerable rate for en-route collision risk (in each dimension), the resulting values of σ, λ and α characterize the worst tolerable NDE distributions for 100 combinations of route systems and occupancy levels.

3.5.5 In order to estimate rates of collision due to the loss of two, three, four, five or six standards of planned separation, the SASP invoked a theory that derives occupancies for pairs of non-adjacent flight paths. This step was necessary because empirical estimates of occupancy — such as those done for the North Atlantic Organized Track System (NAT OTS) — only count as longitudinally proximate, pairs of aeroplanes that are assigned to *adjacent* co-altitude flight paths. When route spacing is large, collisions between aeroplanes assigned to non-adjacent paths contribute little to the total collision rate, and can be ignored. However, when route spacing is small, collisions between aeroplanes assigned to non-adjacent paths can have a significant effect. The theory was presented to the RGCSP in 1999 (Ref. 3), and was later incorporated into the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689), as Appendix 14.

3.5.6 In practice, it is difficult (if not impossible) to directly estimate the parameter α from empirical data on aeroplanes' deviations from their assigned routes, since many (perhaps most) atypical errors are small, and are virtually indistinguishable from typical errors. It is, however, possible for air traffic controllers to identify gross errors, and for air navigation service providers or regional monitoring agencies to estimate the fraction of flight time that the fleet spends committing them. Almost all gross errors are assumed to be atypical errors. As in section 3.4 above, η denotes the fraction of a fleet's flight time that its members spend flying at least half a separation standard (in this case, half of 42.6 km (23 NM), or 11.5 NM) away from the centre lines of their respective assigned routes. The symbol ζ denotes the fraction of the fleet's flight time that its members spend in the vicinity of routes adjacent to their respective assigned routes. The SASP adopted the convention that the vicinity of an adjacent route is the band, centred on that route, whose half-width equals the relevant RNP value of 4 NM. Thus ζ errors were seen to be those whose magnitudes were between 19 NM and 27 NM. Since aeroplanes' lateral deviations were modelled by NDE distributions, reference 5 provided formulas for computing η and ζ as functions of the route spacing and the parameters σ, λ and α. Having determined the parameters of the worst tolerable NDE distributions, the SASP then used them to obtain the maximum tolerable values of η and ζ. They are given in the following tables, each of which has the values relevant to one of the five route configurations considered by the SASP.

3.5.7 Implementation of a lateral separation standard of 42.6 km (23 NM) requires monitoring to ensure that the route system's realized values of η and ζ do not exceed the maximum tolerable values shown in the tables below.

Table 3.5.1. Maximum tolerable values of η and ζ for an RNP 4 fleet using a system of two parallel opposite-direction routes, spaced 42.6 km (23 NM) apart, and oriented so that the aeroplanes on each route have those of the other route on their left.

Occupancy	**Maximum tolerable η**	**Maximum tolerable ζ**
0.1	$1.3541 \cdot 10^{-5}$	$2.8673 \cdot 10^{-6}$
0.2	$6.7790 \cdot 10^{-6}$	$1.4337 \cdot 10^{-6}$
0.3	$4.5252 \cdot 10^{-6}$	$9.5577 \cdot 10^{-7}$
0.4	$3.3983 \cdot 10^{-6}$	$7.1683 \cdot 10^{-7}$
0.5	$2.7221 \cdot 10^{-6}$	$5.7346 \cdot 10^{-7}$
0.6	$2.2714 \cdot 10^{-6}$	$4.7789 \cdot 10^{-7}$
0.7	$1.9494 \cdot 10^{-6}$	$4.0962 \cdot 10^{-7}$
0.8	$1.7079 \cdot 10^{-6}$	$3.5841 \cdot 10^{-7}$
0.9	$1.5201 \cdot 10^{-6}$	$3.1859 \cdot 10^{-7}$
1.0	$1.3698 \cdot 10^{-6}$	$2.8673 \cdot 10^{-7}$
1.1	$1.2469 \cdot 10^{-6}$	$2.6066 \cdot 10^{-7}$
1.2	$1.1444 \cdot 10^{-6}$	$2.3894 \cdot 10^{-7}$
1.3	$1.0577 \cdot 10^{-6}$	$2.2056 \cdot 10^{-7}$
1.4	$9.8344 \cdot 10^{-7}$	$2.0481 \cdot 10^{-7}$
1.5	$9.1905 \cdot 10^{-7}$	$1.9115 \cdot 10^{-7}$
1.6	$8.6270 \cdot 10^{-7}$	$1.7921 \cdot 10^{-7}$
1.7	$8.1299 \cdot 10^{-7}$	$1.6867 \cdot 10^{-7}$
1.8	$7.6879 \cdot 10^{-7}$	$1.5929 \cdot 10^{-7}$
1.9	$7.2925 \cdot 10^{-7}$	$1.5091 \cdot 10^{-7}$
2.0	$6.9367 \cdot 10^{-7}$	$1.4337 \cdot 10^{-7}$

Table 3.5.2. Maximum tolerable values of η and ζ for an RNP 4 fleet using a system of two parallel opposite-direction routes spaced 42.6 km (23 NM) apart, and oriented so that the aeroplanes on each route have those of the other route on their right.

Occupancy	Maximum tolerable η	Maximum tolerable ζ
0.1	$1.0053 \cdot 10^{-5}$	$2.3238 \cdot 10^{-6}$
0.2	$5.0343 \cdot 10^{-6}$	$1.1617 \cdot 10^{-6}$
0.3	$3.3616 \cdot 10^{-6}$	$7.7437 \cdot 10^{-7}$
0.4	$2.5252 \cdot 10^{-6}$	$5.8069 \cdot 10^{-7}$
0.5	$2.0233 \cdot 10^{-6}$	$4.6448 \cdot 10^{-7}$
0.6	$1.6888 \cdot 10^{-6}$	$3.8701 \cdot 10^{-7}$
0.7	$1.4498 \cdot 10^{-6}$	$3.3167 \cdot 10^{-7}$
0.8	$1.2706 \cdot 10^{-6}$	$2.9017 \cdot 10^{-7}$
0.9	$1.1312 \cdot 10^{-6}$	$2.5789 \cdot 10^{-7}$
1.0	$1.0197 \cdot 10^{-6}$	$2.3207 \cdot 10^{-7}$
1.1	$9.2843 \cdot 10^{-7}$	$2.1094 \cdot 10^{-7}$
1.2	$8.5239 \cdot 10^{-7}$	$1.9333 \cdot 10^{-7}$
1.3	$7.8806 \cdot 10^{-7}$	$1.7843 \cdot 10^{-7}$
1.4	$7.3291 \cdot 10^{-7}$	$1.6566 \cdot 10^{-7}$
1.5	$6.8512 \cdot 10^{-7}$	$1.5459 \cdot 10^{-7}$
1.6	$6.4330 \cdot 10^{-7}$	$1.4491 \cdot 10^{-7}$
1.7	$6.0640 \cdot 10^{-7}$	$1.3637 \cdot 10^{-7}$
1.8	$5.7360 \cdot 10^{-7}$	$1.2877 \cdot 10^{-7}$
1.9	$5.4425 \cdot 10^{-7}$	$1.2197 \cdot 10^{-7}$
2.0	$5.1784 \cdot 10^{-7}$	$1.1586 \cdot 10^{-7}$

Table 3.5.3. Maximum tolerable values of η and ζ for an RNP 4 fleet using a system of two parallel same-direction routes, spaced 42.6 km (23 NM) apart.

Occupancy	**Maximum tolerable η**	**Maximum tolerable ζ**
0.1	$1.2272\cdot10^{-4}$	$2.7197\cdot10^{-5}$
0.2	$6.1366\cdot10^{-5}$	$1.3598\cdot10^{-5}$
0.3	$4.0916\cdot10^{-5}$	$9.0651\cdot10^{-6}$
0.4	$3.0691\cdot10^{-5}$	$6.7988\cdot10^{-6}$
0.5	$2.4556\cdot10^{-5}$	$5.4390\cdot10^{-6}$
0.6	$2.0466\cdot10^{-5}$	$4.5325\cdot10^{-6}$
0.7	$1.7545\cdot10^{-5}$	$3.8850\cdot10^{-6}$
0.8	$1.5354\cdot10^{-5}$	$3.3993\cdot10^{-6}$
0.9	$1.3650\cdot10^{-5}$	$3.0216\cdot10^{-6}$
1.0	$1.2287\cdot10^{-5}$	$2.7195\cdot10^{-6}$
1.1	$1.1171\cdot10^{-5}$	$2.4722\cdot10^{-6}$
1.2	$1.0242\cdot10^{-5}$	$2.2662\cdot10^{-6}$
1.3	$9.4553\cdot10^{-6}$	$2.0919\cdot10^{-6}$
1.4	$8.7812\cdot10^{-6}$	$1.9425\cdot10^{-6}$
1.5	$8.1970\cdot10^{-6}$	$1.8130\cdot10^{-6}$
1.6	$7.6857\cdot10^{-6}$	$1.6997\cdot10^{-6}$
1.7	$7.2347\cdot10^{-6}$	$1.5997\cdot10^{-6}$
1.8	$6.8337\cdot10^{-6}$	$1.5108\cdot10^{-6}$
1.9	$6.4750\cdot10^{-6}$	$1.4313\cdot10^{-6}$
2.0	$6.1521\cdot10^{-6}$	$1.3597\cdot10^{-6}$

Table 3.5.4. Maximum tolerable values of η and ζ for an RNP 4 fleet using a system of four parallel same-direction routes, all having the same three flight levels, with 42.6 km (23 NM) between adjacent routes, and with traffic centrally concentrated.

Occupancy	Maximum tolerable η	Maximum tolerable ζ
0.1	$1.0818 \cdot 10^{-4}$	$2.3973 \cdot 10^{-5}$
0.2	$5.4094 \cdot 10^{-5}$	$1.1986 \cdot 10^{-5}$
0.3	$3.6068 \cdot 10^{-5}$	$7.9906 \cdot 10^{-6}$
0.4	$2.7055 \cdot 10^{-5}$	$5.9929 \cdot 10^{-6}$
0.5	$2.1648 \cdot 10^{-5}$	$4.7943 \cdot 10^{-6}$
0.6	$1.8043 \cdot 10^{-5}$	$3.9952 \cdot 10^{-6}$
0.7	$1.5468 \cdot 10^{-5}$	$3.4245 \cdot 10^{-6}$
0.8	$1.3536 \cdot 10^{-5}$	$2.9964 \cdot 10^{-6}$
0.9	$1.2034 \cdot 10^{-5}$	$2.6635 \cdot 10^{-6}$
1.0	$1.0833 \cdot 10^{-5}$	$2.3971 \cdot 10^{-6}$
1.1	$9.8493 \cdot 10^{-6}$	$2.1792 \cdot 10^{-6}$
1.2	$9.0300 \cdot 10^{-6}$	$1.9976 \cdot 10^{-6}$
1.3	$8.3367 \cdot 10^{-6}$	$1.8439 \cdot 10^{-6}$
1.4	$7.7425 \cdot 10^{-6}$	$1.7122 \cdot 10^{-6}$
1.5	$7.2275 \cdot 10^{-6}$	$1.5981 \cdot 10^{-6}$
1.6	$6.7769 \cdot 10^{-6}$	$1.4982 \cdot 10^{-6}$
1.7	$6.3792 \cdot 10^{-6}$	$1.4101 \cdot 10^{-6}$
1.8	$6.0258 \cdot 10^{-6}$	$1.3317 \cdot 10^{-6}$
1.9	$5.7096 \cdot 10^{-6}$	$1.2616 \cdot 10^{-6}$
2.0	$5.4250 \cdot 10^{-6}$	$1.1986 \cdot 10^{-6}$

Table 3.5.5. Maximum tolerable values of η and ζ for an RNP 4 fleet using a system of seven parallel same-direction routes, all having the same seven flight levels, with 42.6 km (23 NM) between adjacent routes, and with traffic centrally concentrated.

Occupancy	Maximum tolerable η	Maximum tolerable ζ
0.1	$9.4634 \cdot 10^{-5}$	$2.0972 \cdot 10^{-5}$
0.2	$4.7324 \cdot 10^{-5}$	$1.0485 \cdot 10^{-5}$
0.3	$3.1555 \cdot 10^{-5}$	$6.9902 \cdot 10^{-6}$
0.4	$2.3670 \cdot 10^{-5}$	$5.2426 \cdot 10^{-6}$
0.5	$1.8940 \cdot 10^{-5}$	$4.1941 \cdot 10^{-6}$
0.6	$1.5786 \cdot 10^{-5}$	$3.4951 \cdot 10^{-6}$
0.7	$1.3533 \cdot 10^{-5}$	$2.9958 \cdot 10^{-6}$
0.8	$1.1844 \cdot 10^{-5}$	$2.6213 \cdot 10^{-6}$
0.9	$1.0530 \cdot 10^{-5}$	$2.3300 \cdot 10^{-6}$
1.0	$9.4785 \cdot 10^{-6}$	$2.0970 \cdot 10^{-6}$
1.1	$8.6184 \cdot 10^{-6}$	$1.9064 \cdot 10^{-6}$
1.2	$7.9017 \cdot 10^{-6}$	$1.7475 \cdot 10^{-6}$
1.3	$7.2952 \cdot 10^{-6}$	$1.6131 \cdot 10^{-6}$
1.4	$6.7754 \cdot 10^{-6}$	$1.4979 \cdot 10^{-6}$
1.5	$6.3248 \cdot 10^{-6}$	$1.3980 \cdot 10^{-6}$
1.6	$5.9306 \cdot 10^{-6}$	$1.3106 \cdot 10^{-6}$
1.7	$5.5828 \cdot 10^{-6}$	$1.2335 \cdot 10^{-6}$
1.8	$5.2736 \cdot 10^{-6}$	$1.1650 \cdot 10^{-6}$
1.9	$4.9970 \cdot 10^{-6}$	$1.1037 \cdot 10^{-6}$
2.0	$4.7480 \cdot 10^{-6}$	$1.0485 \cdot 10^{-6}$

References

1. *Spacing Between PBN Routes, SASP-WG/WHL/23-WP/21, 6 November 2013*
2. *PANS-ATM Amendment for a 42.6 km (23 NM) Lateral Separation Minima, SASP-WG/WHL/25-WP/7, 16 November 2014*
3. *Estimating Occupancy and the Rate of Accidents Due to the Loss of Planned Lateral Separation, for the Individual Components of a System of Parallel Routes, RGCSP-WG/WHL/9-WP/3, 3 November 1999*
4. *The Lateral Overlap Probability Experienced by Aeroplanes Whose Lateral Deviations Follow the Same Normal-Double-Exponential Density, SASP-WG/WHL/11-WP/5, 25 April 2007.*
5. *Maximum Tolerable Rates of Gross Lateral Errors for RNP 4 Fleets Using Systems of Parallel Routes, SASP-WG/26-WP/2, 30 January 2015*

3.6 SAFETY ASSESSMENT FOR 27.8 KM (15 NM) SEPARATION OF NON-INTERSECTING TRACKS — RNP 2 OR IFR GNSS SYSTEM

When implementing the separation specified in this section, the assumptions, enablers, and system performance requirements must be taken into account and compared to the characteristics of the airspace where the separation is being implemented. The assumptions and implementation considerations are listed in the table below:

Assumptions	Implementation considerations
Implementation of a lateral separation standard of 27.8 km (15 NM) requires appropriate monitoring to ensure the rate of lateral deviations larger than 7.5 NM is less than 1E-5 and occupancy does not exceed 0.3 for opposite-direction traffic.	The large lateral deviation (LLD) rate can be expressed as the total time aircraft deviate more than half the separation standard divided by the total flight hours. The “occupancy” is defined as “the parameter of the collision risk model which is twice the count of aircraft proximate pairs in a single dimension divided by the total number of aircraft flying the candidate paths in the same time interval.”
a) presence of relevant serviceable GNSS equipment (Annex 10 compliant) on-board the aircraft; b) equipment and capabilities commensurate with flight crew qualifications; and c) where applicable, authorization from the appropriate authority.	Analyse the aircraft fleet operating in the airspace and issue necessary directives and information concerning navigation equipage in appropriate documentation such as an AIP and/or AIC. GNSS equipage is indicated with the letter “G” in Item 10a of the ICAO FPL. RNP 2 approval also qualifies for the application of the separation.

Assumptions	Implementation considerations
Aircraft fly between designated waypoints on a defined route with knowledge of the nominal track.	Aircraft can be cleared on direct tracks between published waypoints or along published routes. The use of ad hoc latitude/longitude waypoints could be allowed subject to a positive outcome of a safety assessment.
Communications between pilot and controller are at least as good as VHF voice.	
There is no surveillance requirement. Results are intended to apply to a procedural separation environment, however surveillance would reduce the mid-air collision risk calculated by the modelling.	Surveillance should, as a minimum, be by means of position reports provided by the pilot via DCPC VHF voice communications.
A loss of RAIM is assumed to be detected by the pilot, reported to ATC within two minutes, and an alternate navigation means established within five minutes of the start of the outage.	The requirement to report loss of RAIM to ATC should be specified in appropriate documentation such as an AIP or AIC.
The traffic density used had a typical aircraft passing/being passed by 1 same-direction aircraft and 3 opposite-direction aircraft on an adjacent parallel route at the same flight level every flight hour, i.e. $N_x(same) = 1$ and $N_x(opp) = 3$ passings per flight hour were assumed.	Analyse traffic density in the airspace and compare to the assumption.
Aircraft dimensions were risk-conservatively set at Airbus A380 values.	Aircraft smaller than A380 operating in the airspace will yield a lower collision risk.

Safety assessment for navigation performance

3.6.1 The safety assessment for 27.8 km (15 NM) spacing of parallel routes for aircraft equipped with IFR GNSS was based on the Reich model formulae for the rates of collision due to the loss of planned lateral separation: one for a pair of co-altitude parallel flight paths whose traffic moves in the same direction, the other for a pair of co-altitude parallel flight paths whose traffic moves in opposite directions:

$$N_{ac,same} = N_x(same)P_y(S_y)P_z(0)\left(1+\frac{\lambda_x}{\lambda_y}\frac{\overline{|\dot{y}|}}{\overline{|\Delta V|}}+\frac{\lambda_x}{\lambda_z}\frac{\overline{|\dot{z}|}}{\overline{|\Delta V|}}\right) \qquad (3.6.1)$$

$$N_{ac,opp} = N_x(opp)P_y(S_y)P_z(0)\left(1+\frac{\lambda_x}{\lambda_y}\frac{\overline{|\dot{y}|}}{2\overline{V}}+\frac{\lambda_x}{\lambda_z}\frac{\overline{|\dot{z}|}}{2\overline{V}}\right) \qquad (3.6.2)$$

$$N_{ac} = N_{ac,same} + N_{ac,opp} \qquad (3.6.3)$$

3.6.2 The formulae in equations (3.6.1) and (3.6.2) are nearly identical, differing only in the parameters that are sensitive to the direction of flight. They may be referred to as the (equivalent) passing frequency forms of the occupancy forms of the Reich model described in the *Air Traffic Services Manual* (Doc 9426), Appendix B to Part II, Section 2, Chapter 4 (Ref. 1) and in the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689), Appendix 4 (Ref. 2)[3].

3.6.3 The safety assessment was at the 13th Meeting of the Working Group of the Whole of the Separation and Airspace Safety Panel (SASP) (Ref. 3).

3.6.4 The separation minimum was developed to exploit the advanced navigational capabilities of en-route GNSS-equipped aircraft in a VHF voice communications environment, but with no requirement for surveillance to be present. This "sensor-specific" focus did not mean that it was intended to exclude future navigation means. Rather, the restriction to GNSS enabled a clearer assessment of the sources of navigational error. The conclusions could be applied to any other navigation means with performance at least as good as GNSS and the navigational performance was later recognized to be similar to what could be expected of RNP 2-approved aircraft. As a consequence, the SASP decided to publish the separation minima as applicable to both GNSS-equipped aircraft and RNP 2-approved aircraft.

3.6.5 Several assumptions were made during the safety assessment by SASP with regard to the operational scenario and the collision risk model, as described in the following paragraphs.

3.6.6 Aircraft are either GNSS-equipped with integration of the GNSS receiver into the flight management system (FMS) and the cockpit course deviation indicator display, or have GNSS-approved and certified equipment. (The modelling was not intended to apply to aircraft with only an on-board, uncertified hand-held GNSS receiver.)

3.6.7 Aircraft fly between designated waypoints on a defined route with knowledge of the nominal track. A cockpit course deviation indicator (CDI) would show lateral departures from this nominal track.

---

[3] References are numbered 1, 2, 3, ... by section and are listed at the end of each section.

3.6.8 Communications between pilot and controller are at least as good as VHF voice.

3.6.9 There is no surveillance requirement. Results are intended to apply to a procedural separation environment, however surveillance would reduce the mid-air collision risk calculated by the modelling.

3.6.10 Aircraft navigate by GNSS as primary means. The density of ground-based navigation aids may be low.

3.6.11 A RAIM outage is assumed to be detected by the pilot, reported to ATC within two minutes, and an alternate navigation means established within five minutes of the start of the outage.

3.6.12 Both typical and atypical navigational errors were included in the modelling. Typical errors may be present in normal flight. The three sources of typical lateral navigational error included were: GNSS navigational error; navigational error in the event of a RAIM outage; and flight technical error. Suitable types of probability distributions were selected for each navigational error source and their standard deviations were estimated as described in the next five paragraphs.

Typical navigational error

3.6.13 The first source of typical lateral navigational error is GNSS navigational error, i.e. the error that occurs from inaccuracies in the GPS estimation of true position whilst RAIM is available. It is an axisymmetric error. The analogue of a Gaussian distribution in that case is a Rayleigh distribution with cumulative distribution function $F(r) = 1 - e^{-r^2/2\sigma^2}$ where r is radius and σ is the standard deviation of the lateral (and longitudinal) GNSS navigational error.

3.6.14 With guidance from RTCA/DO-229C (Ref. 4), the probability of the GNSS navigational error being greater than 2 NM when RAIM is available was conservatively estimated to be 10^{-3} for en-route flight. This value was used to determine the standard deviation σ. The standard deviation σ which gives a probability of 10^{-3} in the tail $r > 2$ NM is $\sigma = \sqrt{2/(3\ln 10)} = 0.5381$ NM. The lateral error distribution is thus Gaussian with the same standard deviation.

3.6.15 The second source of typical lateral navigational error is that in the event of a RAIM outage. Loss of RAIM is not necessarily associated with a loss of position accuracy. Navigational error during a RAIM outage was conservatively modelled by assuming that a period of RAIM outage is made up of an initial 2 minute period where there is no loss of accuracy followed by a 3 minute period in which positional awareness declines with a 9 degree dead reckoning (DR) splay. The 95 per cent region after the latter is bounded laterally by ± 5.77 NM assuming a 600 kt aircraft speed. A Gaussian distribution was assumed for this lateral error with a zero mean and a standard deviation of 5.77/1.96 = 2.94 NM.

3.6.16 Taking account of navigational error during RAIM outage also requires estimation of the probability of a loss of RAIM occurring. RAIM outages at the en-route 2 NM horizontal protection limit (HPL) level are very rare. The probability of an aircraft being in a RAIM outage at any moment (based on a rate of 10 minutes per year) was $10/(60 \times 24 \times 365.25) = 1.9 \times 10^{-5}$.

3.6.17 The third source of typical lateral navigational error is flight technical error. A cockpit course deviation indicator (CDI) was assumed to be set to show ± 5 NM either side of the nominal track in en-route mode. A pilot (or autopilot) can reasonably be expected to fly within half of the full-scale deflection. A Normal distribution was assumed for this lateral error with a zero mean and a standard deviation of 2.5/1.96 = 1.28 NM, fitted to give a probability of 0.95 inside ± 2.5 NM of the nominal track.

3.6.18 The three error sources described above were used to calculate the probability of lateral overlap $P_y(S_y)$ due to the loss of planned lateral separation and **typical** lateral navigational error. The first step was to combine the GNSS navigational error distribution with RAIM and the navigational error distribution without RAIM into a mixture of two Gaussian distributions. The next step was to add flight technical error, resulting in another mixture of two Gaussian distributions, one representing GNSS navigational error with RAIM and flight technical error, the other representing navigational error without RAIM and flight technical error. Finally, the latter Gaussian mixture distribution was used to calculate the desired probability of lateral overlap $P_y(S_y)$ (Ref. 3).

3.6.19 The Reich model of equations (3.6.1) to (3.6.3) was then used with same- and opposite-direction parallel tracks spaced 27.8 km (15 NM) apart to estimate the collision risk between adjacent aircraft at the same flight level resulting from typical navigational errors. The probability of lateral overlap from the previous paragraph was used. The traffic density used had a typical aircraft passing/being passed by 1 same-direction aircraft and 3 opposite-direction aircraft on an adjacent parallel route at the same flight level every flight hour, i.e. $N_x(same) = 1$ and $N_x(opp) = 3$ passing's per flight hour were assumed. Aircraft dimensions were risk-conservatively set at Airbus A380 values.

3.6.20 Substitution of all the collision risk model parameter values into the model resulted in the collision risk, due to the loss of planned lateral separation and typical lateral navigational error, being estimated as $N_{ac} = 7.68 \times 10^{-10}$ fatal accidents per flight hour. This estimate is well beneath the target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour, leaving some room for collision risk due to the loss of planned lateral separation and atypical navigational error.

Atypical navigational error

3.6.21 Atypical navigational errors include gross operational errors and large uncorrected deviations. They were modelled by a double-exponential distribution and carried through the calculations. One example was given in which the scale parameter of the double-exponential distribution was set conservatively to $\lambda_E = 15$ NM and an atypical error weighting factor $\beta = 2.76 \times 10^{-7}$ led to a risk N_{ac} just under the TLS of 5×10^{-9} fatal accidents per flight hour. The corresponding maximum tolerable error rates are approximately $\eta = 5 \times 10^{-7}$ and $\zeta = 2.7 \times 10^{-8}$. It is therefore possible to have the collision risk under the TLS in 27.8 km (15 NM) lateral separation of RNP 2 aircraft on parallel routes with operational error dominating the risk budget.

Hazard assessment

3.6.22 Refer to section 3.9 and Attachment A for a description of the SASP hazard assessment.

References:

1. *Air Traffic Services Planning Manual*, First (provisional) Edition – 1984, Doc 9426-AN/924.
2. *Manual on Airspace Planning Methodology for the Determination of Separation Minima*, First Edition – 1998, Doc 9689-AN/953.
3. Lateral Separation of GNSS Aircraft based on a 13 km (7 NM) Navigational Tolerance, SASP-WG-WHL/13-WP/49, Montreal, Canada, 12 – 23 May 2008.
4. *Minimum Operational Performance Standards for Global positioning system/Wide Area Augmentation System Airborne Equipment*, RTCA/DO-229C, 2001.

3.7 SAFETY ASSESSMENT FOR THE CLIMB OR DESCENT OF AN RNP 2 OR GNSS AIRCRAFT THROUGH THE FLIGHT LEVEL OF ANOTHER SUCH AIRCRAFT

When implementing the separation specified in this section the assumptions, enablers, and system performance requirements must be taken into account and compared to the characteristics of the airspace where the separation is being implemented. The assumptions and implementation considerations are listed in the table below:

Assumptions	**Implementation considerations**
Direct controller-pilot VHF voice communication is used for the application of the 13 km (7 NM) lateral separation, and third-party communication is used for the application of the 37 km (20 NM) lateral separation.	
Both of the aeroplanes involved in the procedure — that which is climbing or descending, and that which is maintaining its flight level — are assumed to be using the global navigation satellite system (GNSS) to navigate.	Analyse the aircraft fleet operating in the airspace and issue necessary directives and information concerning navigation equipage in appropriate documentation such as an AIP and/or AIC. GNSS equipage is indicated with the letter “G” in Item 10a of the ICAO FPL. RNP 2 approval also qualifies for the application of the separation.

Safety assessment for navigation performance

3.7.1 In modelling the climb or descent of an RNP 2 or GNSS aeroplane through the flight level of another such aeroplane, when both are travelling in the same direction on parallel paths, the SASP sought the minimum lateral separation between the aeroplanes' paths that would permit the procedure to operate safely. A safe operation was viewed as being one in which the risk of collision is less than an established safety criterion, i.e. the target level of safety (TLS). Therefore, the panel approached the problem by deriving an estimate of the procedure's collision risk as a function of the assigned lateral separation between the aeroplanes. It was then able to choose, as a separation standard, the minimum distance for which the risk was tolerably small.

3.7.2 The estimate of the procedure's collision risk used some of the principles of the Reich model; however, its result was not given as a rate of accidents, but rather as the probability of collision in a typical execution of the procedure:

$$\mathrm{Prob}\{collision\} = p_S\left(1+\frac{k_S h}{cw}\right)\left(\frac{l}{m}+\frac{2\sigma h}{cm\sqrt{2\pi}}\right) \qquad (3.7.1)$$

Note— The collision risk model in equation (3.7.1) was presented at the 1th^h Meeting of the Working Group of the Whole of the SASP (Ref. 1)[4].

3.7.3 The symbol p_S in the right-hand side of equation (3.7.1) denotes the probability that, at a randomly chosen moment, aeroplanes whose assigned lateral separation is S nautical miles, are actually in lateral overlap. The other symbols refer to typical aircraft dimensions and relative speeds and separations between the aircraft in the longitudinal and vertical dimensions. They are defined in 3.7.11 and 3.7.12.

3.7.4 In most of the SASP's work on separation minima, the TLS has been stated as a maximum tolerable rate of fatal accidents due to the loss of planned separation (in one or another of the three dimensions), and expressed in units of fatal accidents per flight hour. Since a TLS is generally applied to *all* of the operations in any given airspace, the risk attributable to the climb or descent procedure would be added to the sum of all of that airspace's other estimates of the rate of fatal accidents due to the loss of planned lateral separation. These other estimates would normally vary from one airspace to another; and so the unused risk budget available for the climb or descent procedure would also vary from one airspace to another.

3.7.5 In order to avoid the possibility that different airspace management agencies might impose different separation minima for the procedure, the SASP decided to use another metric for the TLS. In its work on separations for terminal routes the panel had applied a TLS expressed as a maximum tolerable probability of collision for a typical pair of aeroplanes, one arriving at an airport while the other was departing from it. (See Circular 324, 3.5.2 (Ref. 2).) The SASP adopted a similar TLS for its work on the climb or descent procedure, i.e. the maximum tolerable probability of a collision in a typical execution of the procedure. The numerical value of the TLS was taken to be 5×10^{-10}, the same value used for the SASP's work on terminal routes.

---

[4] References are numbered 1, 2, 3, ... by section and are listed at the end of each section.

3.7.6 The collision risk model in equation (3.7.1) was applied for two different cases of communication, namely direct controller-pilot VHF voice communication, and communication through a third party. In 3.7.25, it is explained how these two cases influenced the SASP's choice of values for one of the critical parameters underlying the collision risk model.

3.7.7 The aeroplanes involved in the procedure are assumed to be flying on parallel paths. The SASP also assumed that their longitudinal separation is less than the minimum distance-based separation required of aeroplanes assigned to the same route and flight level. Since one aeroplane passes through the flight level of the other, the pair clearly cannot have any planned vertical separation. Thus the only form of separation prescribed for the procedure is lateral separation.

3.7.8 As is done in the Reich model approach to estimating a rate of collisions, the SASP's collision risk model in equation (3.7.1) conservatively described the aeroplanes as rectangular solids, and viewed a collision as occurring in exactly one of three possible ways: nose-to-tail, top-to-bottom, or side-to-side. A nose-to-tail collision is an entry into longitudinal overlap during a period of simultaneous lateral and vertical overlap; a top-to-bottom collision is an entry into vertical overlap during a period of simultaneous longitudinal and lateral overlap; and a side-to-side collision is an entry into lateral overlap during a period of simultaneous longitudinal and vertical overlap.

3.7.9 Since the aeroplanes are assigned to parallel paths, they do not have any planned longitudinal separation; and so their signed longitudinal separation at the beginning of the climb or descent is taken to be a random variable with an appropriate uniform distribution. Their signed speed difference is assumed to be normally distributed with mean 0.

3.7.10 The probability of a simultaneous longitudinal and vertical overlap between the aeroplanes is a function of the initial longitudinal separation, the speed difference, and several parameters modelled as "constants" (though viewed as constants in the theoretical development, their values were varied, as needed, in the application of the risk equations). In the derivation of the risk equations, the most significant of the constants were the initial vertical separation between the aeroplanes, the height of the rectangular solid used to model an aeroplane, and the speed of the climb or descent. These three values determine the time interval during which a vertical overlap occurs. The value of the random vector (*signed initial longitudinal separation, signed longitudinal speed difference*) determines whether a longitudinal overlap occurs; if so, whether it occurs during the period of vertical overlap; and, if so, the duration of the period of simultaneous overlap.

3.7.11 In the theoretical development, m (nautical miles) denotes the minimum permitted longitudinal separation for aeroplanes assigned to the same route and flight level. The parameters l, w and h respectively denote the length, width and height of the rectangular solid used to model a typical aeroplane. σ denotes the standard deviation of the signed difference between the longitudinal speeds of the aeroplanes; a denotes their initial altitude difference; and c denotes the vertical speed of the climbing or descending aeroplane. t_b and t_e are, respectively, the times at which the vertical overlap begins and ends. They are functions of a, h, and c. In the event that a longitudinal overlap occurs, T_b and T_e respectively denote the times at which it begins and ends. They are functions of the initial longitudinal separation and the signed difference in (longitudinal) speed; and as those are both random variables, so are T_b and T_e.

3.7.12 The symbol p_S denotes the probability that, at a randomly chosen moment, aeroplanes whose assigned lateral separation is S nautical miles, are actually in lateral overlap; and for such aeroplanes, n_S gives the average rate of entry into lateral overlap, measured in occurrences per hour (as long as S is not very close to 0, both p_S and n_S are expected to be extremely small numbers). The parameter k_S (kt) is the average lateral passing speed of aeroplanes that lose their planned lateral separation of S NM.

3.7.13 A nose-to-tail collision occurs when the two aeroplanes involved in the procedure enter into longitudinal overlap while already in vertical and lateral overlap. In order for such a collision to occur, the random time T_b (at which the period of longitudinal overlap begins), must fall between t_b and t_e. The model estimates the probability of such a collision to be $p_S\sigma(t_e - t_b)/\left(m\sqrt{2\pi}\right)$.

3.7.14 A top-to-bottom collision occurs when the two aeroplanes involved in the procedure enter into vertical overlap while already in longitudinal and lateral overlap. The vertical overlap in such a collision must, therefore, begin at a time t_b which is between the random times T_b and T_e. The model estimates the probability of such a collision to be lp_S/m.

3.7.15 A side-to-side collision occurs when the two aeroplanes involved in the procedure enter into lateral overlap while already in longitudinal and vertical overlap. Using a conservative estimate of the average duration of a simultaneous longitudinal and vertical overlap, the model estimates the probability of a side-to-side collision to be $\left(2n_S h/c\right)\left(l/m + \sigma(t_e - t_b)/\left(m\sqrt{2\pi}\right)\right)$. (A summary of some further work on the average duration of a simultaneous longitudinal and vertical overlap is given in reference 3.)

3.7.16 Adding together the probabilities of the three distinct kinds of collision, and simplifying the sum, the model found the probability of a collision, $\text{Prob}\{collision\}$, to be as shown on the right-hand side of equation (3.7.1).

3.7.17 An airspace management authority that measures risk in the traditional unit of fatal accidents per flight hour can use the collision probability to express the procedure's lateral risk in that same unit. If the airspace has an average instantaneous airborne count of f aeroplanes, and the hourly rate at which it executes the climb or descent procedure is R (executions per hour), then the collision risk attributable to the procedure is $2 \times R \times \text{Prob}\{collision\}/f$ fatal accidents per flight hour. This accident rate would be added to the estimated rate of accidents (due to the loss of planned lateral separation) for all other operations in that airspace; and the sum could then be compared to the traditional TLS for the risk due to the loss of planned lateral separation.

3.7.18 Both of the aeroplanes involved in the procedure — the one that is climbing or descending, and the one that is maintaining its flight level — are assumed to be using GNSS to navigate. To account for both typical and atypical behaviour, the SASP modelled the aeroplanes' lateral deviations from their intended paths by using a normal-double-exponential (NDE) probability density function. This density function is typically written as:

$$f(y;\alpha,\sigma_L,\lambda) = \frac{1-\alpha}{\sigma_L\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{y}{\sigma_L}\right)^2} + \frac{\alpha}{2\lambda} e^{-\frac{|y|}{\lambda}} \qquad (3.7.2)$$

3.7.19 The function is a weighted sum of two probability density functions: that of typical errors, taken to be a normal density with mean zero and standard deviation σ_L, and that of atypical errors, taken to be a double-exponential density with mean 0 and standard deviation $\lambda\sqrt{2}$. The parameter α ($0 < \alpha < 1$) is the fraction of flying time during which aeroplanes commit atypical errors.

3.7.20 The SASP derived a formula for $p_S = p_S(\alpha, \sigma_L, \lambda)$, the probability that two such aeroplanes, assigned to parallel paths laterally separated by S nautical miles, are in lateral overlap at a randomly chosen moment (Ref. 4). Using w to denote the width or wingspan of the aeroplanes (as was mentioned above), and Φ to denote the standard normal distribution function, the formula showed that:

$$\begin{aligned}
p_S(\alpha,\sigma_L,\lambda) = {} & (1-\alpha)^2\left[\Phi\left(\frac{w-S}{\sigma_L\sqrt{2}}\right)-\Phi\left(\frac{-w-S}{\sigma_L\sqrt{2}}\right)\right] \\
& +\alpha(1-\alpha)\left\{e^{\frac{\sigma_L^2}{2\lambda^2}}\left[e^{\frac{w-S}{\lambda}}\Phi\left(-\frac{w-S}{\sigma_L}-\frac{\sigma_L}{\lambda}\right)-e^{-\frac{w+S}{\lambda}}\Phi\left(\frac{w+S}{\sigma_L}-\frac{\sigma_L}{\lambda}\right)\right]+\Phi\left(\frac{w-S}{\sigma_L}\right)-\Phi\left(-\frac{w+S}{\sigma_L}\right)\right\} \\
& +\alpha(1-\alpha)\left\{e^{\frac{\sigma_L^2}{2\lambda^2}}\left[e^{\frac{S+w}{\lambda}}\Phi\left(-\frac{S+w}{\sigma_L}-\frac{\sigma_L}{\lambda}\right)-e^{\frac{S-w}{\lambda}}\Phi\left(-\frac{S-w}{\sigma_L}-\frac{\sigma_L}{\lambda}\right)\right]+\Phi\left(\frac{S+w}{\sigma_L}\right)-\Phi\left(\frac{S-w}{\sigma_L}\right)\right\} \\
& +\begin{cases}
\alpha^2+\dfrac{\alpha^2 e^{-\frac{w}{\lambda}}}{2\lambda}\left[S\sinh\left(\dfrac{S}{\lambda}\right)-(w+2\lambda)\cosh\left(\dfrac{S}{\lambda}\right)\right] & \mathit{if}\ S \le w \\
\dfrac{\alpha^2 e^{-\frac{S}{\lambda}}}{2\lambda}\left[(S+2\lambda)\sinh\left(\dfrac{w}{\lambda}\right)-w\cosh\left(\dfrac{w}{\lambda}\right)\right] & \mathit{if}\ w \le S
\end{cases}
\end{aligned} \tag{3.7.3}$$

3.7.21 Using this formula, the SASP computed tables of lateral overlap probability, $p_S(\alpha, \sigma_L, \lambda)$, for two values of σ_L, for ranges of values of S, α, and λ, and for a single empirical estimate of the wingspan w. Three sets of computations were performed, the second and third of them using a larger range of values for S than had been used in the previous set (Refs. 5 to 7). In the computations of $p_S(\alpha, \sigma_L, \lambda)$ used to determine the separation minima applicable to the procedure, the values of S (in NM) were integers from 1 to 30.

3.7.22 The two values of σ_L were based on two levels of performance-based navigation (PBN). One of the PBN levels required the standard deviation of typical errors to be no greater than $0.5/3$ NM $= 1/6$ NM; the other required the standard deviation of typical errors to be no greater than $2.5/3$ NM $= 5/6$ NM. In the absence of empirical data that might suggest an appropriate value of λ, each computation took λ equal to S, which is a conservative approach, in that it (approximately) maximizes the computed lateral overlap probability. The computations yielded two tables of values for $p_S = p_S(\alpha, \sigma_L, \lambda)$ — one table for each assumed value of σ_L — in which each row corresponds to a hypothesized value of S, and each column corresponds to a hypothesized value of α.

3.7.23 In order to obtain tables of collision probability from the tables of lateral overlap probability, the SASP applied equation (3.7.1). Using a longitudinal separation minimum m of 30 NM, empirically estimated values of l, w and h, and conservative values of k_S, c, and σ, it estimated the product of the second and third factors on the right side, $\left(1+\frac{k_S h}{cw}\right)\left(\frac{l}{m}+\frac{2\sigma h}{cm\sqrt{2\pi}}\right)$, to have the value 0.0020838. Multiplying each lateral overlap probability by 0.0020838 then yielded the corresponding collision probability. Thus the SASP obtained two tables of collision probabilities, in which each row corresponded to a hypothesized value of S, and each column corresponded to a hypothesized value of α.

3.7.24 At the smallest values of S – such as 1, 2, 3 or 4 (nautical miles) — the collision probabilities in the table for which $\sigma_L = 5/6$ NM, are several orders of magnitude greater than the corresponding probabilities (those with the same values of S and α) in the table for which $\sigma_L = 1/6$ NM. This is because the lateral overlap probabilities in the former case are dominated by relatively high probabilities of typical ("core") deviations. Once the assigned separation S reaches 13 km (7 NM), the differences between corresponding entries become negligibly small. The SASP, opting for a (very slightly) more conservative approach, chose its minimum separation values from the table (Ref. 7, Table 4) for which $\sigma_L = 5/6$ NM.

3.7.25 The final step in selecting separation minima was to specify suitable values of α, and read from the table the largest value of S for which the collision probability was less than or equal to the TLS value of 5×10^{-10}. After reviewing summaries of North Atlantic performance in recent years, and recognizing that concerted North Atlantic efforts to improve navigation had yielded significant reductions in that region's empirically estimated values of α, the SASP chose values that it believed to be reasonably conservative: $\alpha = 6\times10^{-5}$ when direct controller-pilot communication (DCPC) is available, and $\alpha = 2\times10^{-4}$ when communication between controllers and pilots is accomplished through a third party (see 3.7.8).

3.7.26 Using these values in the table for which $\sigma_L = 5/6$ NM, the SASP found that the pair (S = 7 NM, $\alpha = 6\times10^{-5}$) yielded $\text{Prob}\{collision\} = 4.24\times10^{-10}$, and the pair ($S$ = 20 NM, $\alpha = 2\times10^{-4}$) yielded $\text{Prob}\{collision\} = 4.91\times10^{-10}$. These were the smallest integer values of S for which the collision probabilities (at the chosen values of α) were less than the TLS of 5×10^{-10}. Therefore, the SASP recommended that the climb-or-descent procedure use a lateral separation minimum of 13 km (7 NM) when DCPC is available, and a lateral separation minimum of 37 km (20 NM) when controller-pilot communication is accomplished through a third-party provider of communication services.

3.7.27 For the 13 km (7 NM) separation, an η error is one whose magnitude exceeds 3.5 NM, and a ζ error is one whose magnitude is between 6.67 NM and 7.33 NM. The maximum tolerable gross error rates for the 13 km (7 NM) separation are $\eta = 3.6\times10^{-5}$ and $\zeta = 2.1\times10^{-6}$. For the 37 km (20 NM) separation, an η error is one whose magnitude exceeds 10 NM, and a ζ error is one whose magnitude is between 18.37 NM and 21.63 NM. The maximum tolerable gross error rates for the 37 km (20 NM) separation are $\eta = 1.2\times10^{-4}$ and $\zeta = 1.2\times10^{-5}$.

Hazard assessment

3.7.28 Refer to 3.9 and Attachment A for a description of the SASP hazard assessment.

References:

1. *A Model for Determining the Lateral Separation Needed for One Aeroplane to Pass through Another's Flight Level*, SASP-WG/WHL/13-WP/5, Montreal, Canada, 12 – 23 May 2008.
2. *Guidelines for Lateral Separation of Arriving and Departing Aircraft on Published Adjacent Instrument Flight Procedures*, First Edition – 2010, Cir 324 AN/186, ICAO, Montreal, Canada.
3. *Refinement of the Collision Risk Model for SASP Operational Requirement 20(a)*, SASP-WG/WHL/14-WP/12, Paris, France, 13 – 24 October 2008.
4. *The Lateral Overlap Probability Experienced by Aeroplanes Whose Lateral Deviations Follow the Same Normal-double-Exponential Density*, SASP/WG/WHL/11-WP/5, Montreal, Canada, 21 May – 1 June 2007.
5. *Risk Computations for SASP Operational Requirement 20(a)*, SASP-WG/WHL/14-WP/13, Paris, France, 13 – 24 October 2008.
6. *Risk Computations for SASP Operational Requirement 20(a)*, SASP-WG/WHL/15-WP/3, Montreal, Canada, 25 May – 5 June 2009.
7. *Risk Computations for SASP Operational Requirement 20(a)*, SASP-WG/WHL/18-WP/5, Brussels, Belgium, 8 – 19 November 2010.
8. Appendix I to *Summary of Discussions, Separation and Airspace Safety Panel (SASP), 18th Meeting of the Working Group of the Whole*, SASP-WG/WHL/18-SD, Brussels, Belgium, 8 – 19 November 2010.

3.8 SAFETY ASSESSMENT FOR INTERSECTING TRACKS: 27.8 KM (15 NM) – RNP 2/GNSS, 42.6 KM (23 NM) – RNP 4 AND 93 KM (50 NM) – RNAV 10 (RNP 10)

When implementing the separation specified in this section, the assumptions, enablers, and system performance requirements must be taken into account and compared to the characteristics of the airspace where the separation is being implemented. The assumptions and implementation considerations are listed in the table below:

Assumptions	Implementation considerations
27.8 km (15 NM) separation: a) presence of relevant serviceable GNSS equipment (Annex 10-compliant) on-board the aircraft; b) equipment and capabilities commensurate with flight crew qualifications; and c) where applicable, authorization from the appropriate authority.	Analyse the aircraft fleet operating in the airspace and issue necessary directives and information concerning navigation equipage in appropriate documentation such as an AIP and/or AIC. GNSS equipage is indicated with the letter "G" in Item 10a of the ICAO FPL. RNP 2 approval also qualifies for the application of the separation.

Assumptions	Implementation considerations
27.8 km (15 NM) separation: Aircraft fly between designated waypoints on a defined route with knowledge of the nominal track.	Aircraft can be cleared on direct tracks between published waypoints or along published routes. The use of ad hoc latitude/longitude waypoints could be allowed subject to a positive outcome of a safety assessment.
Communications between pilot and controller are assumed to be such that the aircraft will comply with any climb/descent clearance before/after the specified location. It is assumed that the implementing authority will assess the communication capability requirements (controller intervention capability) for a given application of the separation. (Refer also to the example in 3.8.2.6).	
27.8 km (15 NM) separation: There is no surveillance requirement. Results are intended to apply to a procedural separation environment, however surveillance would reduce the mid-air collision risk calculated by the modelling.	Surveillance should, as a minimum, be by means of position reports provided by the pilot via voice communications.
27.8 km (15 NM) separation: A loss of RAIM is assumed to be detected by the pilot, reported to ATC within two minutes, and an alternate navigation means established within five minutes of the start of the outage.	The requirement to report loss of RAIM to ATC should be specified in appropriate documentation such as an AIP or AIC.
27.8 km (15 NM) separation: The calculations were performed for five crossing pairs of GNSS aircraft per hour with intersection angles from 5 degrees to 175 degrees.	Analyse traffic density in the airspace and compare to the assumption.
30 NM separation: The calculations were performed for five crossing pairs of RNP 4 aircraft per hour with intersection angles from 5 degrees to 175 degrees.	Analyse traffic density in the airspace and compare to the assumption.

Assumptions	Implementation considerations
93 km (50 NM) separation: Calculations were performed for five crossing pairs of RNAV 10 (RNP 10) aircraft per hour with intersection angles from 5 degrees to 175 degrees.	Analyse traffic density in the airspace and compare to the assumption.

3.8.1 Overview

3.8.1.1 Lateral separation minima for aircraft on intersecting tracks have traditionally been available for VOR, NDB, dead reckoning and RNAV operations in the PANS-ATM, 5.4.1.2.1.2. In addition, the PANS-ATM used to provide a method of applying lateral separation for "RNAV operations (where RNP is specified) on intersecting tracks or ATS routes" based on the concept of a defined area of conflict around the intersection. The area of conflict is a quadrilateral, the corners of which are known as lateral separation points, defined as the points on a track where the perpendicular distance to the other track is equal to the lateral separation minimum. Lateral separation is achieved by the controller ensuring that two aircraft will not be simultaneously within the area of conflict at the same level (Ref. 1)[5]. This particular method of applying lateral separation on intersecting tracks was included in the PANS-ATM and in the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689).

3.8.1.2 An alternative method of applying lateral separation on intersecting tracks based on a "protected" region of airspace either side of the track of a reference aircraft (aircraft 1) was presented at the 13th Meeting of the Working Group of the Whole of the Separation and Airspace Safety Panel (SASP) (Ref. 2). A second aircraft flying on an intersecting track and which did not have longitudinal or vertical separation with the reference aircraft, would be required to change level before entering the protected region, and not to return to the original level until clear of the protected region. See Figure 3-8-1.

---

[5] References are numbered 1, 2, 3, ... by section and are listed at the end of each section.

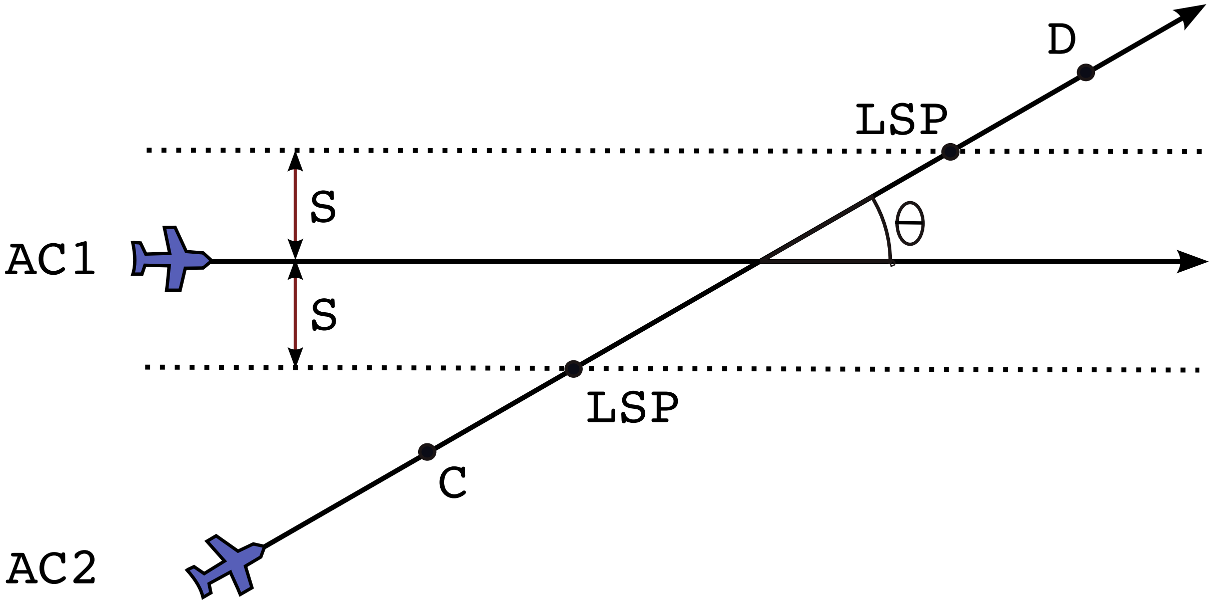

Figure 3-8-1. Two aircraft are at the same flight level on intersecting tracks. To assure separation, aircraft 2 will be required to climb/descend at C and reach another level by its first lateral separation point (LSP). Similarly, past the track of aircraft 1, aircraft 2 could descend/climb only after its second LSP is reached. Position D shows where aircraft 2 would regain its original flight level.

3.8.1.3 The SASP saw several operational advantages of the alternative method over the area of conflict method and agreed to amend both the PANS-ATM and the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689) by replacing the area of conflict method by the alternative protected region method at the 19th Meeting of its Working Group of the Whole (Ref. 3).

3.8.1.4 Calculations of the collision risk for various PBN navigation specifications were performed using the methodology in reference 1 as applied to the protected region scenario depicted in Figure 3-8-1. The collision risk for aircraft crossing at a particular intersection was evaluated from

$$CR(t_0,t_1) = 2.NP.\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1} HOP(t\,|\,V_1,V_2)\,P_z\big(h(t)\big)\left(\frac{2V_{rel}}{\pi\lambda_{xy}}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right)g_1(V_1)g_2(V_2)dt.dV_1dV_2 \qquad (3.8.1)$$

The model calculates the collision risk $CR(t_0,t_1)$, expressed in fatal accidents per flight hour, over a time interval $[t_0,t_1]$ where at time t_0 aircraft 2 is at some point with a lead distance to C corresponding to 10 minutes. Similarly, at time t_1 aircraft 2 is at a distance beyond D corresponding to 10 minutes.

3.8.1.5 Most of the parameters in equation (3.8.1) have their usual meaning, e.g. aircraft speeds and dimensions ($V_1, V_2, V_{rel}, \overline{|\dot{z}|}, \lambda_{xy}, \lambda_z$), aircraft speed error probability densities $(g_1(V_1), g_2(V_2)$), the probability of vertical overlap ($P_z(h(t))$), and the number of aircraft pairs passing an intersection per flight hour (*NP)* (Refs. 1 and 2).

3.8.1.6 The main parameter of the collision risk model in equation (3.8.1) is the conditional probability $HOP(t \mid V_1, V_2)$ of horizontal overlap at time t given the aircraft speeds V_1 and V_2. Apart from its dependence on time t and the aircraft speeds V_1 and V_2, the horizontal overlap probability $HOP(t \mid V_1, V_2)$ depends critically on the along-track and across-track navigational error distributions and the distance of the reference aircraft (aircraft 1) to the intersection at time t_0.

3.8.1.7 The collision risk calculations performed for the protected region method of lateral separation on intersecting tracks (ref. 2) departed from those for the area of conflict method (Ref. 1) in that the risk was calculated with different starting positions for the reference aircraft at time t_0, including both sides of the intersection. For each intersection angle, a **maximum** collision risk was found over all starting positions of the reference aircraft, and over all combinations of 300, 480, and 600 knots aircraft ground speeds.

3.8.1.8 Collision risk was calculated for two intersecting-tracks lateral separation minima and three navigation specifications, namely:

a) 27.8 km (15 NM) and RNP 2;

b) 27.8 km (15 NM) and RNP 4; and

c) 93 km (50 NM) and RNAV 10 (RNP 10).

Details of the three cases are provided below. The cases differ (mainly) with regard to the modelling of the navigational error distributions. Since not every reader may be interested in the same or all cases, each case is described in a separate subsection that may be read independently of the other cases.

3.8.2 27.8 km (15 NM) and RNP 2 and GNSS

3.8.2.1 A safety assessment for 27.8 km (15 NM) intersecting-tracks lateral separation was presented at the 13th Meeting of the Working Group of the Whole of the SASP (Ref. 2).

3.8.2.2 The 27.8 km (15 NM) lateral separation minimum on intersecting tracks was developed to exploit the advanced navigational capabilities of en-route GNSS-equipped aircraft with no requirement for ATS surveillance to be present. This “sensor-specific” focus did not mean that it was intended to exclude future navigation means. Rather, the restriction to GNSS enabled a clearer assessment of the sources of navigational error. The conclusions could be applied to any other navigation means with performance at least as good as GNSS and the navigational performance was later recognized to be similar to what could be expected of RNP 2-approved aircraft. As a consequence, the SASP decided to publish the separation minima as applicable to both GNSS-equipped aircraft and RNP 2-approved aircraft.

3.8.2.3 Several assumptions were made during the safety assessment by SASP with regard to the operational scenario and the collision risk model.

3.8.2.4 Aircraft are either GNSS-equipped with integration of the GNSS receiver into the FMS and the cockpit course deviation indicator display, or have GNSS-approved and certified equipment. The modelling was not intended to apply to aircraft with only an on-board, uncertified hand-held GNSS receiver.

3.8.2.5 Aircraft fly between designated waypoints on a defined route with knowledge of the nominal track. A cockpit course deviation indicator (CDI) would show lateral departures from this nominal track.

3.8.2.6 Communications between pilot and controller are assumed to be such that the aircraft will comply with any climb/descent clearance before/after the specified location. It is assumed that the implementing authority will assess the communication capability requirements (controller intervention capability) for a given application of the separation.

Example: (refer to Figure 3-8-1)

Scenario 1:

AC1 is at F230 and AC2 is at F250. AC2 is cleared to descend to F210 after passing the second lateral separation point (LSP) in the figure.

Scenario 2:

Both aircraft are at F230. AC2 is cleared to climb to F250 before passing the first LSP in the figure.

From a communication performance point of view these are two very different situations that are handled differently by ATC procedures. In Scenario 2 the controller should not let AC2 run close to the LSP before issuing the climb clearance unless he has reliable communications, whereas in Scenario 1 the reliability of the communications is not as important from a controller intervention capability point of view because the aircraft are vertically separated to start with.

3.8.2.7 There is no surveillance requirement. Results are intended to apply to a procedural separation environment, however surveillance would reduce the mid-air collision risk calculated by the modelling.

3.8.2.8 Aircraft navigate by GNSS as primary means. The density of ground-based navigation aids may be low.

3.8.2.9 A RAIM outage is assumed to be detected by the pilot, reported to ATC within two minutes, and an alternate navigation means established within five minutes of the start of the outage.

3.8.2.10 Both typical and atypical navigational errors were included in the modelling. Typical errors may be present in normal flight. Three sources of typical lateral and longitudinal navigational error are: GNSS navigational error; navigational error in the event of a RAIM outage; and flight technical error. Suitable types of probability distributions were selected for each navigational error source and their standard deviations were estimated as described in the next five paragraphs. A description of the modelling of navigational error in the event of a RAIM outage is included for the sake of completeness, but the possibility of a RAIM outage was ignored in the calculations due to the short duration of the crossing procedure.

Typical navigational error

3.8.2.11 The first source of typical navigational error is GNSS navigational error, i.e. the error that occurs from inaccuracies in the GPS estimation of true position whilst RAIM is available. It is an axisymmetric error. The analogue of a Gaussian distribution in that case is a Rayleigh Distribution with cumulative distribution function $F(r) = 1 - e^{-r^2/2\sigma^2}$ where r is radius and σ is the standard deviation of the lateral and longitudinal GNSS navigational error.

3.8.2.12 With guidance from RTCA 229C (Ref. 4), the probability of the GNSS navigational error being greater than 2 NM when RAIM is available was conservatively estimated to be 10^{-3} for en-route flight. This value was used to determine the standard deviation σ. The standard deviation σ which gives a probability of 10^{-3} in the tail $r > 2$ NM is $\sigma = \sqrt{2/(3\ln 10)} = 0.5381$ NM. The lateral and longitudinal error distributions are thus Gaussian with the same standard deviation.

3.8.2.13 The second source of typical navigational error is that in the event of a RAIM outage. Loss of RAIM is not necessarily associated with a loss of position accuracy. Lateral navigational error during a RAIM outage was conservatively modelled by assuming that a period of RAIM outage is made up of an initial 2-minute period where there is no loss of accuracy followed by a 3-minute period in which positional awareness declines with a 9 degree dead reckoning (DR) splay. The 95 per cent region after the latter is bounded laterally by ± 5.77 NM assuming a 600 kt aircraft speed. A Gaussian distribution was assumed for this lateral error with a zero mean and a standard deviation of 5.77/1.96 = 2.94 NM.

3.8.2.14 Taking account of navigational error during RAIM outage also requires estimation of the probability of a loss of RAIM occurring. RAIM outages at the en-route 2 NM horizontal protection limit (HPL) level are very rare. The probability of an aircraft being in a RAIM outage at any moment (based on a rate of 10 minutes per year) was $10/(60\times 24\times 365.25) = 1.9\times 10^{-5}$.

3.8.2.15 The third source of typical navigational error is flight technical error. For the lateral dimension, a cockpit course deviation indicator (CDI) was assumed to be set to show ± 5 NM either side of the nominal track in en-route mode. A pilot (or autopilot) can reasonably be expected to fly within half of the full-scale deflection. A Gaussian distribution was assumed for this lateral error with a zero mean and a standard deviation of 2.5/1.96 = 1.28 NM, fitted to give a probability of 0.95 inside ± 2.5 NM of the nominal track. The same distribution was used for the longitudinal error.

3.8.2.16 The probability distributions for the first and third error sources described above were used for the calculation of the probability of horizontal overlap $HOP(t \mid V_1, V_2)$ due to the loss of planned horizontal separation and **typical** lateral navigational error in the collision risk model of equation (3.7.1) (Ref. 2).

3.8.2.17 The collision risk model of equation (3.7.1) was then used in reference 2 with a protected area of width 27.8 km (15 NM) either side of the nominal track of the reference aircraft (aircraft 1) and both aircraft initially at the same flight level. An additional buffer was included in the requirements on the manoeuvring aircraft (aircraft 2). A climb or descent of 2 000 ft was required to have completed a tolerance distance 13 km (7 NM) before the nominal track of aircraft 2 crossed the protected area of aircraft 1. A similar tolerance distance was added to the far side of the protected region before aircraft 2 could begin returning to the same level as aircraft 1. Double-exponentially distributed speed errors were included for each aircraft with a very large scale parameter value of 80 kt.

3.8.2.18 The calculations were performed for five crossing pairs of GNSS aircraft per hour with intersection angles from 5 degrees to 175 degrees. For each intersection angle, the **maximum** collision risk was calculated over all starting positions of aircraft 1 and over all combinations of 300, 480 and 600 kt aircraft speeds. The largest (maximum) collision risks were found for 5 degree and 175 degree intersection angles. These were of the order of 10^{-19} fatal accidents per flight hour when speed errors were not included and of the order of 5×10^{-19} fatal accidents per flight hour when speed errors were included, reflecting the increased uncertainty of aircraft position and the increased chance of overlap in case of speed errors. Clearly, these values are well below a target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour.

3.8.2.19 Additional calculations for GNSS-equipped aircraft without the additional 13 km (7 NM) buffer for the manoeuvring aircraft (aircraft 2) were reported in section 4 of reference 5. The calculations were again performed for five crossing pairs of GNSS aircraft per hour with intersection angles from 5 degrees to 175 degrees. As before, for each intersection angle, the **maximum** collision risk was calculated. The largest (maximum) collision risk was of the order of 10^{-18} without speed errors and 10^{-17} when speed errors with a scale parameter value of 20 kt were included. These values are well below a target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour. The largest (maximum) values occurred again for the extreme angles of 5 degrees and 175 degrees.

3.8.2.20 The collision risk model of equation (3.7.1) was also applied to the 27.8 km (15 NM) lateral separation minimum and an RNAV 2 aircraft population in reference 5. The main difference with the calculations described in the previous two paragraphs concerned the navigation error distributions. For RNAV 2, the along-track and across-track navigational error distributions were assumed double-exponential with the scale parameter based on a 95 per cent navigation containment condition at the RNAV value of 2 NM. Thus, $\lambda_A = \lambda_C = -2/\log(0.05) = 0.6676$ NM. Calculations were performed without and with speed errors, where in the latter case a scale parameter value of 5.82 kt was used (based on equation 3.7.1).

3.8.2.21 For each intersection angle, the **maximum** collision risk was calculated over all starting positions of aircraft 1 and over all speed combinations of the two aircraft from 300, 480 and 600 kt, for intersection angles between 5 degrees and 175 degrees. The largest (maximum) collision risks were again found for the extreme angles of 5 degrees and 175 degrees, 1.56×10^{-10} and 1.81×10^{-10} fatal accidents per flight hour, respectively. The collision risk values for all other angles were at least two orders of magnitude below a TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.2.22 Based on the target level of safety being met for an RNAV 2 aircraft population and a 27.8 km (15 NM) intersecting-tracks lateral separation minimum, it was concluded that this separation minimum would also be safe for an RNP 2 aircraft population. In fact, calculations performed during the 17th Meeting of the Working Group of the Whole of the SASP showed that the collision risk for an RNP 2 aircraft population and a lateral separation minimum as low as 6 NM would give a collision risk comfortably beneath the TLS (Ref. 6).

Atypical navigational error

3.8.2.23 The most likely high-consequence operational error was identified as aircraft 2 failing to reach a vertically separated level by the edge of the protected area and continuing through the track of aircraft 1 at the same flight level. For a single pair of GNSS aircraft and a protected area half-width of 27.8 km (15 NM) and for a number of angles, the maximum collision risk was approximately 0.02 (unpublished). This conditional risk infers a maximum tolerable rate of one operational error per 4 million executions of the procedure in order for the procedure to satisfy a TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.2.24 The operational errors are essentially the same for the protected area scenario as they are for PANS-ATM, 5.4.1.2.1.2. For angles other than 90 degrees, the protected area method of lateral separation provides greater protection against operational error than the PANS-ATM, 5.4.1.2.12 method since the distance from the intersection at which aircraft 2 climbs or descends is greater (see 3.7.7). It is also possible to require a buffer before (and after) the protected area to further reduce the collision risk.

3.8.3 27.8 km (15 NM) and RNP 4

3.8.3.1 A safety assessment for 27.8 km (15 NM) intersecting-tracks lateral separation and RNP 4 aircraft was presented at the 14th Meeting of the Working Group of the Whole of the SASP (Ref. 5). Both typical and atypical navigational errors were included in the modelling.

Typical navigational error

3.8.3.2 Typical errors may be present in normal flight and were modelled on the basis of the navigation specification. Along-track and across-track navigational error distributions were chosen Gaussian with a standard deviation based on the more stringent navigation at twice the RNP value (8 NM). Thus, $\sigma_A = \sigma_C = 8/4.46 = 1.7937$ NM. The probability distributions for the navigational errors were used for the calculation of the probability of horizontal overlap $HOP(t \mid V_1, V_2)$ due to the loss of planned horizontal separation and typical lateral navigational error in the collision risk model of equation (3.7.1) (Ref. 5).

3.8.3.3 The collision risk model of equation (3.7.1) was then used in reference 5 with a protected area of width 27.8 km (15 NM) either side of the nominal track of the reference aircraft (aircraft 1) and both aircraft initially at the same flight level. A climb or descent of 2 000 ft was required to be completed before the nominal track of aircraft 2 crossed the protected area of aircraft 1. Similarly, a descent or climb of 2 000 ft was required not to be started before the nominal track of aircraft 2 crossed the far boundary of the protected area of aircraft 1. Double-exponentially distributed speed errors were included for each aircraft. Two scale parameter values were used, namely 5.82 kt and 20 kt.

3.8.3.4 The calculations were performed for five crossing pairs of RNP 4 aircraft per hour with intersection angles from 5 degrees to 175 degrees. For each intersection angle, the **maximum** collision risk was calculated over all starting positions of aircraft 1 and over all combinations of 300, 480 and 600 kt aircraft speeds. Collision risk values were found to be well below a target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour. The effect of the speed distributions was small. The largest (maximum) collision risks were found for 5 degree and 175 degree intersection angles. These were of the order of 2×10^{-10} fatal accidents per flight hour.

Atypical navigational error

3.8.3.5 The most likely high-consequence operational error was identified as aircraft 2 failing to reach a vertically separated level by the edge of the protected area and continuing through the track of aircraft 1 at the same flight level. For a single pair of RNP 4 aircraft and a protected area half-width of 27.8 km (15 NM) and for a number of angles, the maximum collision risk was approximately 0.01 (Ref. 7). This conditional risk infers a maximum tolerable rate of one operational error per 2 million executions of the procedure in order for the procedure to satisfy a TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.3.6 The operational errors are essentially the same for the protected area scenario as they are for PANS-ATM 5.4.1.2.1.2. For angles other than 90 degrees the protected area method of lateral separation provides greater protection against operational error than the PANS-ATM, 5.4.1.2.12 method since the distance from the intersection at which aircraft 2 climbs or descends is greater (Ref. 7). It is also possible to require a buffer before (and after) the protected area to further reduce the collision risk.

3.8.4 93 km (50 NM) and RNAV 10 (RNP 10)

3.8.4.1 The safety assessment for intersecting-tracks lateral separation and RNAV 10 (RNP 10) started at the 14th Meeting of the Working Group of the Whole of the SASP (Ref. 5).

3.8.4.2 It started off with examining the feasibility of a **27.8 km (15 NM)** lateral separation minimum for RNAV 10 (RNP 10) aircraft. Calculations were performed with the model of equation (3.7.1) for Gaussian as well as double-exponential navigational error distributions, these distributions being used for the calculation of the probability of horizontal overlap $HOP(t \mid V_1, V_2)$ parameter of the collision risk model. Calculations were performed for five crossing pairs of RNAV 10 (RNP 10) aircraft per hour with intersection angles from 5 degrees to 175 degrees. For each intersection angle, the **maximum** collision risk was calculated over all starting positions of aircraft 1 and over all combinations of 300, 480 and 600 kt aircraft speeds.

3.8.4.3 For the more optimistic Gaussian case, it was found that with the inclusion of an additional buffer of 13 km (7 NM) either side of the protected area of aircraft 1, the (maximum) collision risk for each intersection angle between 5 degrees and 175 degrees was larger than 10^{-7}, with the largest values being as large as 10^{-3}.

3.8.4.4 The calculations for the Gaussian case were then extended to separation minima of 25, 30, and 40 NM, combined with the 13 km (7 NM) buffer. The (maximum) collision risk values were found to be (well) below the target level of safety (TLS) of 5×10^{-9} fatal accidents per flight hour only for the 40 NM minimum (plus the 13 km (7 NM) buffer).

3.8.4.5 Based on the above results, collision risk calculations for double-exponential navigational error distributions started with lateral separation minima of 30 NM and 40 NM and the additional 13 km (7 NM) buffer. All collision risk values were found to (considerably) exceed the TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.4.6 Thus, using double-exponential error distributions, lateral collision risk was calculated for a lateral separation minimum of 93 km (50 NM) and no buffer. The (maximum) collision risk estimates for intersection angles between 40 and 135 degrees inclusive were less than the TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.4.7 It was then recognized that the maximization over all aircraft 1 starting positions was over-conservative and that there were many previous analyses which averaged over the possible starting positions of aircraft 1.

3.8.4.8 Results for 93 km (50 NM) intersecting-tracks lateral separation and RNAV 10 (RNP 10) aircraft based on the collision risk model of equation (3.7.1) with **averaging** over the starting position of aircraft 1 rather than maximization over that position were presented at the 15th Meeting of the SASP (Ref. 7). Both typical and atypical navigational errors were included in the modelling.

Typical navigational error

3.8.4.9 Typical errors may be present in normal flight and were modelled on the basis of the navigation specification. Along-track and across-track navigational error distributions were chosen double-exponential with a scale parameter based on a 95 per cent navigation containment condition at the RNAV value of 10 NM. Thus, $\lambda_A = \lambda_C = -10/\ln(0.05) = 3.338$ NM. The probability distributions for the navigational errors were used for the calculation of the probability of horizontal overlap $HOP(t \mid V_1, V_2)$ due to the loss of planned horizontal separation and **typical** lateral navigational error in the collision risk model of equation (3.7.1) (Ref. 7).

3.8.4.10 The RNAV 10 (RNP 10) collision risk calculations proceeded with a protected area of width 93 km (50 NM) either side of the nominal track of the reference aircraft (aircraft 1) and both aircraft initially at the same flight level. A climb or descent of 2 000 ft was required to be completed before the nominal track of aircraft 2 crossed the protected area of aircraft 1. Similarly, a descent or climb of 2 000 ft was required not to start before the nominal track of aircraft 2 crossed the far boundary of the protected area of aircraft 1. Speed errors were not included in the calculations because of their very high computational load in case of double-exponential navigational error distributions.

3.8.4.11 The calculations were performed for five crossing pairs of RNP 10 aircraft per hour with intersection angles from 15 degrees to 165 degrees. The intersection angles were restricted to this range because very small and very large angles are not well-suited to lateral separation by the protected region method. For such angles, aircraft 2 would be required to change level very far before the intersection. For each intersection angle, the collision risk was calculated for all starting positions of aircraft 1, maximized over all combinations of 300, 480 and 600 kt aircraft speeds, and subsequently averaged over the starting position of aircraft 1.

3.8.4.12 Analysis of the collision risk as a function of the starting position of aircraft 1 showed that averaging over a fixed interval of this position was unsuitable for all angles (Ref. 7). Thus, the range of aircraft 1 starting positions used for the collision risk averaging was chosen as the range over which collision risk was more than 1 per cent of the peak value. A second and simpler averaging method was applied at the smallest and largest angles, viz. averaging over 100 NM either side of the starting position of aircraft 1 which gave the maximum risk.

3.8.4.13 Using the combination of averaging methods described in the previous paragraph, the averaged collision risk was found to be less than the TLS of 5×10^{-9} fatal accidents per flight hour for intersection angles between 25 degrees and 150 degrees inclusive.

3.8.4.14 It was concluded that modelling of the navigational performance of RNAV 10 (RNP 10) aircraft was apparently very conservative since these aircraft routinely pass each other (at 0 and 180 degrees) with a lateral separation standard of 93 km (50 NM) (the protected area half-width used here). It should also be noted that PANS-ATM, 5.4.1.2.1.2 allows two RNAV 10 aircraft on intersecting tracks to be at the same flight level provided at least one aircraft is 27.8 km (15 NM) or more from the intersection point.

Atypical navigational error

3.8.4.15 The most likely high-consequence operational error was identified as aircraft 2 failing to reach a vertically separated level by the edge of the protected area and continuing through the track of aircraft 1 at the same flight level. For a single pair of RNAV 10 (RNP 10) aircraft and a protected area half-width of 93 km (50 NM) and for a number of angles, the maximum collision risk was approximately 0.007 (unpublished). This conditional risk infers a maximum tolerable rate of one operational error per 1.4 million executions of the procedure in order for the procedure to satisfy a TLS of 5×10^{-9} fatal accidents per flight hour.

3.8.4.16 The operational errors are essentially the same for the protected area scenario as they are for PANS-ATM, 5.4.1.2.1.2. For angles other than 90 degrees the protected area method of lateral separation provides greater protection against operational error than the PANS-ATM, 5.4.1.2.12 method since the distance from the intersection at which aircraft 2 climbs or descends is much greater (Ref. 7).

Hazard assessment

3.8.5.1 Refer to section 3.9 and Attachment A for a description of the SASP hazard assessment.

References:

1. *A Collision Risk Model Based On Reliability Theory That Allows For Unequal Navigation Accuracy*, SASP-WG/WHL/7-WP/20 REVISED, Montreal, Canada, 9 – 20 May 2005.
2. *Lateral Separation of GNSS Aircraft based on a 7 NM Navigational Tolerance*, SASP-WG-WHL/13-WP/49, Montreal, Canada,12 – 23 May 2008.
3. *Summary of Discussions Separation and Airspace Safety Panel (SASP) 19th Meeting of the Working Group of the Whole,* SASP-WG/WHL/19-SD, Montreal, Canada, 23 May – 2 June 2011.
4. *Minimum Operational Performance Standards for Global positioning system/Wide Area Augmentation System Airborne Equipment*, RTCA/DO-229C, 2001.
5. *Application of SASP-WG/WHL/13-WP/49 Methodology to RNP 4, RNAV 2 and RNAV 10 (RNP 10) Intersecting Tracks*, SASP-WG/WHL/14-WP/44, Paris, France, 13 – 24 October 2008.
6. *RNP 2 lateral Separation on Intersecting Tracks in a Protected Airspace Context,* SASP/WG/WHL/17- Flimsy/07, Montreal, Canada, 10 – 21 May 2010.
7. *Lateral separation on Intersecting Tracks in a Protected Airspace Context*, SASP/WH/WHL/15-WP/28, Montreal, Canada, 25 May – 5 June 2009.

3.9 HAZARD ASSESSMENT

3.9.1 As was stated in 3.3.2, the SASP safety assessment comprises two parts, namely, the risk due to navigation performance and the risk due to other hazards. With the description of the safety assessment for navigation performance having been completed in the previous paragraphs, the following paragraphs deal briefly with the safety assessment for the other hazards.

3.9.2 In an effort to identify hazards that may affect the implementation and use of published separation minima and to develop effective controls for these hazards, SASP undertook a process of hazard identification. The intent of this activity was to bring operational experience and issues into the development of a separation minimum. The identified hazards are documented in the Implementation Hazard Log in Attachment A.

Note.— SASP hazard identification is limited in its scope, and is intended to identify significant globally applicable hazards and to develop specific controls that shall be considered in separation minima development. This activity should **not** *be considered as a formal hazard identification process that would normally include the determination of severity and estimates of likelihood and requires complementary regional, State or local implementation safety assessment action.*

3.10 CONCLUSIONS

3.10.1 The application of the SASP process demonstrated that the separation minima developed and detailed in this document have been determined as being safe. SASP also identified a number of hazards together with appropriate mitigations and controls.

3.10.2 Notwithstanding the above, there is a requirement for a region or State to undertake an implementation safety assessment. In principle, this comprises two parts, namely, a safety assessment for navigation performance and a hazard assessment. In practice, only a hazard assessment needs to be performed for any local implementation since the safety assessment for the navigation performance under the various navigation specifications is valid for any implementation. The hazard analysis is to identify hazards and related mitigation measures that are specific to the local situation.

3.10.3 To assist regions and States with their implementation safety assessment, a State implementation plan is provided in the next chapter. This plan relies upon the various outputs from the application of the SASP safety assessment.

Chapter 4

IMPLEMENTATION CONSIDERATIONS

4.1 INTRODUCTION

4.1.1 The successful implementation of the proposed separation minima is not possible at the regional, State or local level without undertaking an implementation safety assessment (see Chapter 3). When undertaking this activity, reference should be made to the requirements detailed in *Annex 11 — Air Traffic Services* (Chapter 2, 2.26), PANS-ATM (Chapter 2, 2.6), and the guidance material contained in the *Safety Management Manual (SMM)* (Doc 9859), including the development of hazard identification, risk management and mitigation procedures tables.

4.1.2 This chapter provides an overview of the minimum steps that SASP considers necessary for a region or State or ANSP to undertake a safety assessment.

4.2 IMPLEMENTATION CONSIDERATIONS

When undertaking a regional, State or local safety assessment, the following step-by-step process is provided as guidance:

Step 1: Undertake widespread regional consultation with all possible stakeholders and other interested parties.

Step 2: Develop an airspace design concept or ensure that the proposed separation minima being implemented will fit the current airspace system and regional or State airspace planning strategy.

Step 3: Review this circular noting specific assumptions, constraints, enablers and system performance requirements.

Step 4: Compare assumptions, enablers, and system performance requirements in this circular with the regional or State's operational environment, infrastructure and capability.

Step 5: If a region or State or ANSP has determined that the change proposal for that region or State is equal to or better than the reference, requirements and system performance in this circular, then the region or State must undertake safety management activities including:

a) formal hazard and consequence(s) identification and safety risk analysis activities, including identification of controls and mitigators;

b) an implementation plan;

c) techniques for hazard identification/safety risk assessment which may include:

    1) the use of data or experience with similar services/changes;

    2) quantitative modelling based on sufficient data, a validated model of the change, and analysed assumptions;

    3) the application and documentation of expert knowledge, experience and objective judgement by specialist staff; and

    4) a formal analysis in accordance with appropriate safety risk management techniques as set out in the *Safety Management Manual (SMM)* (Doc 9859).

d) identification and analysis of human factors issues identified with the implementation including those associated with human-machine interface matters;

e) simulation where appropriate;

f) operational training; and

g) regulatory approvals.

Step 6: If a region or State has determined that the change proposal for that region or State is not equal to the requirements and system performance in this circular, then the region or State must:

a) consider alternative safety risk controls to achieve the technical and safety performance that matches the reference in this circular; or

b) conduct appropriate quantitative risk analysis for the development of a local standard in accordance with the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689).

Step 7: Develop suitable safety assessment documentation including a safety plan and associated safety cases.

Step 8: Implementation activities should include:

a) trial under appropriate conditions;

b) expert panel to undertake scrutiny of proposals and development of identified improvements to the implementation plan;

c) develop an appropriate backup plan to enable reversion if necessary; and

d) continuous reporting and monitoring results of incidents, events and observations.

Step 9: Develop suitable post-implementation monitoring and review processes.

ATTACHMENT A

IMPLEMENTATION HAZARD LOG

This section lists some hazards that were considered by the SASP when developing the PBN lateral separation minima. The pertinent ATS authority must, in its implementation safety assessment, review these hazards and reflect how they may affect its local implementation and additionally identify if there are other regional, State or local hazards that need to be considered (refer to 3.2 and 3.9 of the main text).

Definitions:

Hazard:

A hazard is defined as a condition or an object with the potential to cause injuries to personnel, damage to equipment or structures, loss of material, or reduction of ability to perform a prescribed function.

Subject 1 — Application of Separation
Hazard Loss of separation.
Unsafe Event (cause) A failure of the process by which controllers apply lateral separation based on the cleared route, position reports, pilot reported distances from waypoints/fixes and climb/descend clearances with restrictions. Those methods are designed to ensure that, when applying lateral separation, aircraft are never separated by less than the applicable minima.
Analysis The distances specified in PANS-ATM, 5.4.1.2.1.6 and 5.4.1.2.1.7 are minimum separation values. In reality, aircraft are often (most of the time) spaced by larger values when applying this separation. The track geometry depends on local airspace design. Minima close to the intersecting track standard could effectively be used in association with altitude restrictions such as “maintain an altitude until a certain position” or “reach an altitude by a certain position”. Controllers apply the lateral separation based on: a) the cleared route of the aircraft; and b) position reports; and c) reported distances from a waypoint or a fix; and when required

d) a climb/descent clearance with a restriction.

It is important to note that controllers are not required to determine the actual ground distance between any two aircraft when applying this type of lateral separation. In the case of non-intersecting tracks, the controller determines the distance between the tracks as measured perpendicular between the track centre lines. In the case of intersecting tracks, the controller ensures that at least one of the aircraft does not get closer to the track of the other aircraft than the applicable minimum lateral separation unless longitudinal or vertical separation exists.

In many (or most) cases, in normal operations, aircraft will be separated by more than the required minimum separation.

SASP global controls and/or mitigators

SASP has done a collision risk assessment that demonstrates that the estimated collision risk based on the use of the lateral separation discussed in this document is sufficiently small (refer to Chapter 3 for a description of the collision risk assessment).

Regional and local controls and/or mitigators required

1) All instances of loss of separation related to this separation minima must be reported and investigated.

2) The ATS authority intending to apply this separation must ensure that the airspace and route design is such that the application of this separation is practicable.

3) The ATS authority intending to apply this separation must ensure that the amount of traffic is not more than can be safely handled by this type of separation.

4) The ATS authority intending to apply this separation must ensure that appropriate training concerning the application of separation is provided to controllers.

Subject 2 — Communications

Hazard

Loss of separation.

Unsafe Event (cause)

Use of inappropriate communication media.

Analysis

For some of the lateral separation standards, the communication media is explicitly described in the PANS-ATM, whereas for other standards the determination of the required communication is left to the appropriate authority. Using appropriate communication media is paramount in ensuring the timely communication of clearances to aircraft for intervention purposes.

The application of lateral separation requires the necessary clearances be communicated to the pilot in a timely manner to ensure that alternative separation is established before lateral separation is eroded. The communication media and the reliability of the media are also important in ensuring that the controller has the required intervention capability when an actual or potential loss of separation is detected. Additionally, the amount of traffic being handled in the airspace must not be more than what can be safely handled by communication infrastructure.

The possible permutations in the application of lateral separation are many and the SASP does not consider it feasible to prescribe for all the lateral separation minima, on a globally applicable basis, the communication to be used in each case. This task is left to the appropriate ATS authority to determine when the communication requirements are not specified with the separation minima.

SASP global controls and/or mitigators

a) Where communication requirements are not specified for the application of separation minima, it is the responsibility of the appropriate ATS authority to determine these requirements by means of an appropriate safety assessment for each area of application.

Prior to and during the application of any separation minimum, the controller must consider the adequacy of the available communications, considering the time element required to receive replies from two or more aircraft, and the overall workload/traffic volume associated with the application of such minima.

b) Application of performance-based communication should be in accordance with the *Performance Based Communication and Surveillance (PBCS) Manual* (Doc 9869, in preparation).

c) Data link procedures should be in accordance with the *Global Operational Data Link (GOLD) Manual* (Doc 10037).

d) SATCOM procedures should be in accordance with the *Satellite Voice Operations Manual (SVOM)* (Doc 10038, in preparation).

Regional and local controls and/or mitigators required

1) Perform an implementation safety assessment.

2) Provide appropriate training to controllers regarding communication procedures and communication performance.

Subject 3 — Area Navigation

Hazard

Loss of separation.

Unsafe Event (cause)

A lack of awareness of the specifics of the difference between “TO-TO” and “TO-FROM” navigation may result in a controller incorrectly applying intersecting-track lateral separation.

Analysis

The GNSS receiver functions differently compared to conventional avionics receivers (i.e. DME).

a) The GNSS receiver presents data to the pilot in reference to the waypoint the aircraft is approaching. Once an aircraft passes this waypoint, the GNSS receiver again sequences the next waypoint as the “active” waypoint, and all information displayed is in reference to this new waypoint. This is referred to as “TO-TO” navigation.

b) Some aircraft navigating using GNSS are not capable of flying an outbound track from a waypoint. Those aircraft always have to track towards a waypoint.

c) In some cases, after passing flyover waypoints, the aircraft will not join a track from the flyover waypoint but rather join a track direct towards the next waypoint.

While the concept of “TO-TO” navigation may pose a potential hazard, the safety analysis shows that technical risks are limited. The change from “TO-FROM” navigation to the “TO-TO” navigation introduces changes to the pilot’s perspective in regard to their tools, tasks, and associated procedures and how the controller applies the separation. Those issues need to be addressed by means of training and awareness initiatives.

SASP global controls and/or mitigators

Paragraph 5.4.1.1.4 has been added to the PANS-ATM stating that “When an aircraft turns onto an ATS route via a flyover waypoint, a separation other than the normally prescribed lateral separation shall be applied for that portion of the flight between the flyover waypoint where the turn is executed and the next waypoint (see Figures 5-1 and 5-2).”

Regional and local controls and/or mitigators required

1) Any risk associated with the different behaviour of area navigation systems as opposed to conventional VOR/NDB/DME systems should be mitigated by means of training and awareness initiatives. This is the responsibility of the appropriate ATS authority.

2) ATC should, whenever practicable, request distance to the next waypoint. Nevertheless, pilots should be advised by means of AICs or State AIPs, that position reports from other than “TO” waypoints may be requested by ATC for the purpose of track- and distance-based separation. To this end, pilots should be reminded to be familiar with their avionics equipment so that this information can be provided as soon as practicable. It is the responsibility of the appropriate ATS authority to issue the appropriate guidance material to pilots. The following is an example of a suitable text for this purpose:

   GNSS avionics typically display the distance to the next waypoint. To ensure proper separation between aircraft, a controller may request the distance from a waypoint that is not the currently active waypoint in the avionics; it may even be behind the aircraft. Pilots should be able to obtain this information from the avionics. Techniques vary by manufacturer, so pilots should ensure familiarity with this function.

3) When establishing lateral separation points, it is important that coordination is effected among air traffic control, airspace planners and procedure designers when ATC require a lateral separation point to be published as a named waypoint.

Subject 4 — Database integrity

Hazard

Loss of separation.

Unsafe Event (cause)

Loss of integrity in a database may result in incorrect waypoint information in the aircraft and ATM system navigation database.

Analysis

Database integrity issues are common to all aspects of area navigation and to the application of all separation minima that employ area navigation. This issue is therefore not specific to the application of lateral separation.

With the implementation of area navigation procedures, the handling of navigation data is a significant aspect of safe operations. Its importance increases as operations move away from traditional procedures and routes based on flying “to and from” ground-based NAVAIDs. Database integrity relies on minimizing errors throughout the entire data chain, commencing with surveying, through procedure design, data processing and publication, data selection, coding, packing processes and up to the replacement of on-board data. The latter occurs as often as every 28-day AIRAC cycle, and in the future may become a near real time activity.

Modern ATM systems also employ navigation databases. Database errors may result in incorrect results from conflict probes and could therefore lead to loss of separation.

International efforts are currently in progress to ensure database integrity by the introduction of new database quality control procedures. Refer Annex 15 and RTCA document DO-200A.

SASP global controls and/or mitigators

None.

Regional and local controls and/or mitigators required

a) The appropriate ATS authority must ensure that appropriate quality control procedures are followed at all levels of the data chain to ensure database integrity in aircraft and ATM systems.

b) Where available, the flight data processing system should make use of ADS-C data for route conformance monitoring (refer to the *Global Operational Data Link (GOLD) Manual* (Doc 10037).

Subject 5 — Incorrect waypoint

Hazard

Loss of separation.

Unsafe Event (cause)

Pilots providing distance and track information with reference to the “wrong” waypoint.

Analysis

With the multitude of waypoints stored in the navigation system database, there is a possibility that a pilot will provide distance in reference to an incorrectly selected waypoint or fly a track to an incorrectly selected waypoint. The resulting position information will be erroneous and could result in loss of separation.

This risk exists with the application of any area navigation type procedure. There are numerous procedures that require pilots to navigate to waypoints, and report distances or progress in regard to waypoints imbedded in their databases. When lateral separation is used between area navigation aircraft, the separation can be erroneous when pilots report the distance or track in regard to the wrong waypoint.

It is paramount that controllers and pilots use standard phraseology when obtaining and giving track and distance reports. This helps in minimizing the possibility of errors.

SASP global controls and/or mitigators

Specific phraseology for obtaining and reporting distance from navaids and waypoints is published in PANS-ATM, 12.3.1.9.

Regional and local controls and/or mitigators required

a) Pilots and controllers should be advised by means of respective directives, circulars, manuals and training the importance of including the name of the waypoint when reporting the distance to/from that waypoint.

b) Where available, the flight data processing system should make use of ADS-C data for route conformance monitoring (refer to the *Global Operational Data Link (GOLD) Manual* (Doc 10037).

Subject 6 — Incorrect waypoint entry

Hazard

Loss of separation.

Unsafe Event (cause)

A manual waypoint entry error results in navigation to an incorrect waypoint.

Analysis

Navigation systems allow pilots to create waypoints manually in the en-route mode. This presents the possibility that pilots may enter waypoint co-ordinates incorrectly.

CPDLC enables ATC to uplink route information into the area navigation system. This presents the possibility that ATC may uplink an incorrect waypoint.

Pilots and ATC sometimes have to create ad hoc latitude/longitude waypoints in the absence of predefined waypoints or air routes. The risk of entering such waypoints incorrectly into the ATC- or navigation system increases as the number of digits defining the waypoint increases. The risk of manually entering very complex waypoints such as 6521.9N01312.6W may be too high in the context of applying lateral separation. There may be a high risk of misunderstanding when communicating such waypoints between controller and pilot.

SASP global controls and/or mitigators

None.

Regional and local controls and/or mitigators required

a) The appropriate ATS authority should design the airspace and air routes in such a way that the requirement to use manually created latitude/longitude waypoints is avoided. This can be done by publishing waypoints and airways/routes in a manner that aids the application of lateral separation.

b) Where available, the flight data processing system should make use of ADS-C data for route conformance monitoring (refer to the *Global Operational Data Link (GOLD) Manual* (Doc 10037).

c) Where available, CPDLC uplink message UM137 CONFIRM ASSIGNED ROUTE and consequential aircraft response DM40 ASSIGNED ROUTE [route clearance] is a means for ATC to confirm the intended route of the aircraft. The route conformance process can be automated in the FDPS.

Subject 7 — Filing of incorrect FPL information

Hazard

Loss of separation.

Unsafe Event (cause)

A navigation specification, which the aircraft and aircrew is not approved for, and/or incorrect navigation, communication or surveillance equipment is filed in the FPL.

Analysis

The safety analysis used for determining the lateral separation standards was based on the assumption that the concerned aircraft and crew had the required approvals and had correctly filed the approvals and the on-board navigation equipment and, where applicable, communication and surveillance equipment. If an incorrect approval or incorrect navigation, communication or surveillance equipment is filed in the FPL, then the controller could apply inappropriate separation.

Aircraft operators need to obtain an approval for the aircraft and aircrew to operate in accordance with a specified PBN specification, RCP specification and RSP specification. After this approval has been granted, the operator is allowed to file in the FPL the appropriate designator for the navigation, communication and surveillance specification.

Aircraft operators are required to correctly file the on-board navigation, communication and surveillance equipment that is serviceable and useable by the crew.

ATC reads the navigation, communication, surveillance and equipment designators from the FPL and apply separation accordingly. ATC normally does not question the data in the FPL and trusts that the filed data are correct.

It is important that aircraft operators and aircrew understand the importance of obtaining the appropriate operational approvals and filing correct data in the FPL, and the adverse impact that incorrectly filing this information can have on airspace risk.

SASP global controls and/or mitigators

The following guidance material is published by ICAO:

1) *Performance-based Navigation (PBN) Manual* (Doc 9613) providing guidance concerning area navigation, navigation specifications and operational approvals.

2) *Performance Based Communication and Surveillance (PBCS) Manual* (Doc 9869) providing guidance concerning communication and surveillance specifications and operational approvals.

3) PANS-ATM providing guidance for completing the FPL form.

4) This circular providing guidance on implementation of lateral separation.

Regional and local controls and/or mitigators required

The appropriate ATS authority should ensure that aircraft operators are granted operational approvals in accordance with the PBN and PBCS Manuals.

Subject 8 — Errors in interpreting FPL information

Hazard

Loss of separation.

Unsafe Event (cause)

The air traffic controller applies an incorrect separation as a consequence of misinterpreting the FPL information.

Analysis

The safety analysis used for determining the lateral separation standards was based on the assumption that the ATM system or air traffic controller reads the navigation specification, communication specification, surveillance specification and navigation equipment information from the FPL and applies the appropriate separation standard. A mistake in interpreting the FPL information may lead to the controller applying inappropriate separation.

Aircraft operators file the on-board navigation, communication and surveillance equipment and operational approvals in the FPL. The air traffic controller or the ATM system reads this information from the FPL and applies separation accordingly.

Increasing complexities of navigation, communication and surveillance information in the FPL may lead to mistakes in reading and interpreting the FPL navigation, communication and surveillance data leading to application of incorrect separation standards and the adverse impact on airspace risk.

SASP global controls and/or mitigators

The following guidance material is published by ICAO:

1) *Performance-based Navigation (PBN) Manual* (Doc 9613) providing guidance concerning area navigation, navigation specifications and operational approvals.

2) *Performance Based Communication and Surveillance (PBCS) Manual* (Doc 9869) providing guidance concerning communication and surveillance specifications and operational approvals.

3) PANS-ATM providing guidance for completing the FPL form.

4) This circular providing guidance on implementation of lateral separation.

Regional and local controls and/or mitigators required

1) ATM systems should display aircraft navigation, communication and surveillance capabilities to the controller in a clear and unambiguous manner.

2) When conflict probe systems are used they should automatically interpret the navigation, communication and surveillance information in the FPL.

Subject 9 — GNSS outage

Hazard

Loss of separation.

Unsafe Event (cause)

GNSS failure affecting multiple aircraft or a failure of individual GNSS receivers.

Analysis

The effect of a failure of an individual GNSS receiver or a failure affecting multiple aircraft will have different impacts on the ATM system.

GNSS outages are detected by RAIM equipment. If an individual GNSS receiver fails, the pilot shall advise ATC if the failure results in the aircraft no longer being able to navigate using the GNSS signal or no longer being able to satisfy an applicable navigation specification. Controllers will then apply other forms of separation that are not reliant on GNSS. This is no different from a traditional avionics equipment failure.

Local GNSS outages are possible, for example during periods of GNSS signal interference. Pilots cannot distinguish interference from loss of GNSS integrity, so again they would simply advise ATC that they are receiving a RAIM warning, and ATC would again apply a different form of separation. Following further RAIM warning reports from other pilots in the area, controllers should suspect that interference may be occurring, and shall not use GNSS for separation.

SASP global controls and/or mitigators

1) Navigation specifications in the PBN Manual (Doc 9613) detail that the pilot shall inform ATC when the aircraft can no longer satisfy the navigation requirements applicable to the navigation specification being employed in the airspace.

2) The following paragraph is contained in PANS-ATM:

> "5.4.1.1.3 When information is received indicating navigation equipment failure or deterioration below the navigation performance requirements, ATC shall then, as required, apply alternative separation methods or minima."

Regional and local controls and/or mitigators required

The appropriate ATS authority must consider the effect of GNSS outages in their contingency plans.

Subject 10 — An aircraft fails to meet a restriction

Hazard

Loss of separation.

Unsafe Event (cause)

A pilot does not comply with an ATC clearance.

Analysis

When applying lateral separation, controllers may instruct pilots to climb/descend after passing a specific position or may instruct pilots to climb/descend to reach a flight level/altitude before passing a certain position or distance from a fix. It is the responsibility of the pilot to judge whether such a clearance can be met and to advise ATC if unable to comply.

When applying lateral separation to aircraft on intersecting tracks, controllers can use the following means to effect the separation:

a) clear aircraft to reach a certain level before the lateral separation point;

b) clear aircraft to descend/climb to a certain level after passing the lateral separation point.

There may be several reasons that a pilot fails to meet such a clearance:

a) pilot overestimates the rate-of-climb/descend capability of the aircraft;

b) the aircraft is not able to reach a certain altitude because of temperature, turbulence, etc.

c) the pilot forgets to initiate a climb/descent at the correct time/position.

d) the pilot misunderstands the clearance/instruction/restriction.

Ultimately, it is the responsibility of the pilots to judge if they can safely comply with a clearance/instruction/restriction.

All those issues are common to the application of any separation minima. This issue is therefore not specific to the application of lateral separation,

SASP global controls and/or mitigators

None.

Regional and local controls and/or mitigators required

The appropriate ATS authority should include the appropriate application methods of lateral separation in controller training programmes.

Subject 11 — Misunderstanding in communicating the clearance to the aircraft

Hazard

Loss of separation.

Unsafe Event (cause)

Pilot misunderstands the clearance.

Analysis

There is a possibility that a pilot could misunderstand a clearance and therefore fly a different flight profile than was intended by the controller to effect proper separation. This can result in loss of separation.

Air traffic controllers must communicate clearances to aircraft. Some clearances are simple while other clearances are complex. There are various means of communication: VHF, UHF, HF, CPDLC, and SATCOM. The quality of communications varies and language barriers exist between pilots and controllers with different native tongues. All of these and more issues can influence the likelihood of a misunderstanding in communicating a clearance to the aircraft.

There are many things that can lead to misunderstanding and mishearing in ATC communications. Examples are:

a) bad quality of communications (static, noise, etc.);

b) lack of English language proficiency;

c) bad radiotelephony procedures;

d) non-standard phraseologies; and

e) non-standard CPDLC procedures and misunderstanding of CPDLC message elements.

All those issues are common to any ATC communications and application of any separation minima. No communication issue seems to be specific to the application of lateral separation.

SASP global controls and/or mitigators

1) Standard voice phraseology is published in PANS-ATM, Chapter 12.

2) Standard CPDLC procedures and message elements are published in the *Global Operational Data Link Document (GOLD) Manual* (Doc 10037).

3) Standard SATCOM procedures are published in the *Satellite Voice Operations Manual (SVOM)* (Doc 10038).

Regional and local controls and/or mitigators required

The appropriate ATS authority should enforce the use of standard phraseologies and standard CPDLC and SATCOM procedures in pilot-controller communications.

Subject 12 — Airspace design and fly-by turns

Hazard

Loss of separation.

Unsafe Event (cause)

The separation being applied does not accommodate the expected variability in the performance of area navigation systems executing fly-by turns.

Analysis

Most waypoints in area navigation are fly-by waypoints. By design this involves the aircraft turning before reaching the waypoint and completing the turn without ever flying over the waypoint. The distance from the fly-by waypoint at which an aircraft commences and terminates the fly-by turn depends on many factors, i.e. the magnitude of the turn, aircraft speed, altitude, wind velocity, etc.

Because lateral separation of aircraft is measured between the centre lines of the nominal cleared track, turning aircraft may not be on the expected track and could result in loss of separation.

Document Eurocae ED-75C/ RTCA DO-236C, "*MASPS Required Navigation Performance for Area Navigation*" issued in December 2003 deals with fly-by turns. This document contains guidance material for navigation systems operating in an RNAV environment and provides guidance for the development of airspace and operational procedures. In 3.2.5.4, the document deals with the issue of fly-by transitions (turns) and provides formulas for deriving fly-by transition areas based on assumptions of ground speed and roll angle. Flyby theoretical transition (turn) areas can only be derived for turns up to 120 degrees for low altitude transitions and turns up to 70 degrees for high altitude transitions.

However, it should be noted that monitoring of aircraft performing fly-by turns has revealed that some aircraft perform turns that take the aircraft outside the theoretical transition area mentioned above.

SASP global controls and/or mitigators

None.

Regional and local controls and/or mitigators required

1) The turning behaviour of RNAV aircraft must be included in the training curriculum of air traffic controllers.
2) The turning behaviour of RNAV aircraft must be accounted for in airspace design.

Subject 13 — Strategic Lateral Offset Procedure (SLOP)

Hazard

Loss of separation.

Unsafe Event (cause)

Pilot applies an offset that exceeds the SLOP criteria.

Analysis

The strategic lateral offset procedure (SLOP) is published in PANS-ATM, 16.5. The procedure allows the appropriate authority to authorize a SLOP of up to 2 NM in airspace where lateral separation or route spacing is 42.6 km (23 NM) or more and a SLOP up to 0.5 NM where lateral separation or route spacing is between 6 NM and 42.6 km (23 NM).

If one or both aircraft apply a lateral offset that is larger than the values specified above in the direction of the other aircraft, the result could be significant erosion of the actual separation between the aircraft.

SASP global controls and/or mitigators

a) The SLOP is published in PANS-ATM, 16.5.
b) Guidance material for implementation of SLOP is contained in Circular 331.

Regional and local controls and/or mitigators required

a) Implementation of strategic lateral offset procedures shall be coordinated between the States involved.
b) The routes or airspace where application of strategic lateral offsets is authorized, and the procedures to be followed by pilots, shall be published in aeronautical information publications (AIPs) and promulgated to air traffic controllers.

— END —

ISBN 978-92-9249-832-0
9 789292 498320