Cir 331
AN/192

Implementation of Strategic Lateral Offset Procedures

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FOREWORD

When reduced vertical separation minimum (RVSM) was implemented and the uptake of global navigation satellite system (GNSS) became apparent, the Oceanic Air Navigat5ion Service Providers (ANSPs) became aware that the risk of mid-air collision was increasing exponentially. RVSM altimetry puts an aircraft within an average of 10 m (33 ft) vertically and GNSS puts that same aircraft within approximately 9 m (30 ft) laterally of where they are supposed to be. The obvious solution to reduce the vertical overlap risk in the system to meet the Target Level of Safety was to reduce the vertical overlap probability by recreating the randomness that RVSM and GNSS had removed from aircraft distribution. The result was the implementation of a lateral offset in increments of one mile of up to 3.7 km (2 NM) to the right. This has been used in the oceans for a decade. One additional benefit is that it provides a wake turbulence avoidance capability.

The risk of mid-air collisions in non-oceanic airspace prompted several organizations to request ICAO to adapt the strategic lateral offset procedure (SLOP) to a surveillance environment. Utilizing the extreme accuracy of GNSS and newer aircraft’s ability to offset in tenths of a mile, multiple offsets up to one half mile may be applied safely within route separations as low as 11.1 km (6 NM).

The mitigation of risk that this creates in the air traffic system will allow ANSPs to continue to meet the target levels of safety.

The content of this circular was developed over a period of two years by a group of experts on separation and airspace safety comprising of pilots, air traffic controllers, aircraft operators, air navigation service providers and regulators from different States, international organizations and ICAO regions.

This Circular provides insight into the development of SLOP, including discussion of all the safety analyses.

ACRONYMS AND ABBREVIATIONS

AIC	Aeronautical information circular
AIP	Aeronautical information publication
AIRAC	Aeronautical information regulation and control
AIS	Aeronautical information service
ANSP	Air Navigation Service Provider
AOC	Aircraft offset capability
ASOC	Advanced-strategic offset concept
ASLOP	Advanced-strategic lateral offset procedure
ATC	Air traffic control
ATS	Air traffic services
CPDLC	Controller-pilot data link communications
DCPC	Direct controller-pilot communication
DME	Distance measuring equipment
FAA	Federal Aviation Administration
FD	Fault detection
FDE	Fault detection and exclusion
FL	Flight level
FMS	Flight management system
GAPAN	Guild of air pilots and air navigators
GLONASS	Global navigation satellite system
GNSS	Global navigation satellite system
GPS	Global positioning system
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
INS	Inertial navigation system
IP	Information paper
NDB	Non-directional beacon
NM	Nautical mile
PANS-ATM	Procedures for air navigation services – air traffic management
PIRG	Planning and implementation regional group
RAIM	Receiver autonomous integrity monitoring
RGCSP	Review of the General Concept of Separation Panel
RNAV	Area navigation
RNP	Required navigation performance
RVSM	Reduced vertical separation minimum
SASP	Separation and Airspace Safety Panel
SBAS	Satellite-based augmentation system
SLOP	Strategic lateral offset procedure
TCAS	Traffic alert and collision avoidance system
WGS-84	World Geodetic System – 1984
WG	Working Group
WG/WHL	Working Group of the Whole
WP	Working paper

Chapter 1

OVERVIEW

1.1 INTRODUCTION

1.1.1 The purpose of this circular is to provide information on the work undertaken by the Review of the General Concept of Separation Panel (RGCSP), the Separation and Airspace Safety Panel (SASP), and planning and implementation regional groups (PIRGs) to establish the offset values and procedures to be used in applying strategic lateral offsets. The purpose of such offsets is to mitigate the increasing collision risk resulting from improved navigation and altimetry performance. This increased risk is a result of the improved accuracy and use of global navigation satellite system (GNSS) and the adoption of reduced vertical separation minimum (RVSM) compliant altimetry systems.

1.1.2 This circular is aimed at a worldwide audience among civil aviation authorities and air navigation service providers responsible for airspace management as well as aircraft operators and aircrew.

1.2 SCOPE

1.2.1 The material in this circular is limited to the application of the strategic lateral offset procedures (SLOP) in the en-route environment.

1.3 DEVELOPMENT OF STRATEGIC LATERAL OFFSET PROCEDURES

1.3.1 In November 2000 ICAO published the first of three State letters requesting comments on the Strategic Lateral Offset Procedures. That letter proposed offsets of 1.9 km (1 NM) to the right of track, applied by GNSS aircraft only, and used in systems of parallel routes separated by at least 93 km (50 NM). The offsets could only be applied when authorized by air traffic control (ATC).

1.3.2 This proposal was a start but failed to provide for the alleviation of the effects of wake turbulence. The guidelines were not successful in mitigating the risk of lateral overlap since they merely moved the centre line one mile. There were also other concerns that needed to be addressed.

1.3.3 On receipt of the first State letter, the North Atlantic Mathematicians Working Group formed a committee to develop the improvements they felt were necessary to make lateral offsets achieve the risk mitigations and wake avoidance capabilities that were desired. One problem was the requirement for ATC authorization. The air navigation service providers (ANSPs) did not want the responsibility nor the increased workload that such authorizations would create. After consultation between the NAT SPG and the ICAO Secretariat, it was agreed to propose the amendment of the NAT section of Regional Supplementary Procedures (Doc 7030) to allow pilots to initiate offsets without having to report them, so that use of the procedure would be entirely transparent to controllers.

1.3.4 The second State letter dated May 2002, stated that the authorization required by Annex 2 — Rules of the Air, paragraph 3.6.2.1.1, prior to a pilot's application of a lateral offset, could be achieved by coordinated publication of approved offset procedures, by NOTAMs and by notices in Aeronautical Information Publications (AIP), by all States concerned. Action should also be taken to incorporate the procedures in the Regional Supplementary Procedures (Doc 7030). The NAT SPG proceeded to implement a lateral offset procedure under guidelines in its portion of Doc 7030, resulting in the third State letter.

1.3.5 The third State letter was issued in August 2004. The guidelines published in the State letter were based on safety assessments and procedures developed by SASP. These procedures, which were known as the Strategic Lateral Offset Procedures (SLOP), were subsequently implemented in various oceanic areas throughout the world.

1.3.6 SLOP was subsequently published in the Procedures for Air Navigation Services — Air Traffic Management (PANS-ATM, Doc 4444) and was only applicable in Oceanic and remote continental airspace. The offsets were restricted to 1.9 km (1NM) or 3.7 km (2 NM) right of centre line with maintaining the centre line also remaining as the third option. The application of the procedure was restricted to airspace where the lateral separation was 55.5 km (30 NM) or more.

1.3.7 A mid-air collision in South America in 2006 prompted ICAO to amend the SASP work programme to develop a solution similar to the SLOP for the domestic en-route environment. Guild of Air Pilots and Air Navigators (GAPAN) and International Federation of Airline Pilots Associations (IFALPA) also supported that notion and urged ICAO to act as quickly as possible on this subject.

1.3.8 The idea quickly emerged to employ the capability of some modern aircraft to offset in fractions of a mile for this purpose. Both Boeing and Airbus announced that all their future aircraft would have the capability to offset in tenths of a mile and it was therefore clear that using such "micro-offsets" to mitigate the collision risk would be viable in the future.

1.3.9 SASP subsequently conducted safety assessments to establish that application of micro-offsets as great as 0.9 km (0.5 NM) to the right of centre line would be safe in airspace where lateral separation or route spacing is at least 11.1 km (6 NM).

1.3.10 The extreme accuracies of modern navigation systems reduce the random lateral separations between aircraft aiming to fly on the same route. When a gross error eliminates all planned separation between two aircraft, in the longitudinal or vertical dimension, the reduced probability of random separation in the lateral dimension makes a collision far more likely than it would have been in the past, when an aircraft's lateral deviations from route centre line were far greater. The use of lateral offsets is a means of increasing the random lateral separation between aircraft that aim to fly along the same route.

1.3.11 Errors are rare but they do occur. Aircraft are sometimes flown at flight levels other than those expected by the controller, therefore, allowing aircraft to fly self-selected lateral offsets provides an additional safety margin and mitigates the risk of a mid-air collision when non-normal events such as aircraft navigation errors, height deviation errors and turbulence induced altitude-keeping errors do occur. It has been shown that collision risk is significantly reduced by the application of these offsets.

Chapter 2

DESCRIPTION OF THE NEW STRATEGIC LATERAL OFFSET PROCEDURES

2.1 PANS-ATM PROVISIONS

2.1.1 This circular addresses the implementation of the following strategic lateral offset procedures published in the PANS-ATM, Section 16.5.

16.5 STRATEGIC LATERAL OFFSET PROCEDURES (SLOP)

Note 1.– SLOP are approved procedures that allow aircraft to fly on a track parallel to the right of the centre line relative to the direction of flight to mitigate the lateral overlap probability due to increased navigation accuracy, and wake turbulence encounters. Unless specified in the separation standard, an aircraft's use of these procedures does not affect the application of prescribed separation standards.

Note 2.– Annex 2, 3.6.2.1.1, requires authorization for the application of strategic lateral offsets from the appropriate ATS authority responsible for the airspace concerned.

16.5.1 Implementation of strategic lateral offset procedures shall be coordinated among the States involved.

Note.— Information concerning the implementation of strategic lateral offset procedures is contained in the Implementation of Strategic Lateral Offset Procedures (Circ 331).

16.5.2 Strategic lateral offsets shall be authorized only in en-route airspace as follows:

a) where the lateral separation minima or spacing between route centre lines is 55.5 km (30 NM) or more, offsets to the right of the centre line relative to the direction of flight in tenths of a nautical mile up to a maximum of 3.7 km (2 NM); and

b) where the lateral separation minima or spacing between route centre lines is 11.1 km (6 NM) or more and less than 55.5 km (30 NM), offsets to the right of the centre line relative to the direction of flight in tenths of a nautical mile up to a maximum of 0.9 km (0.5 NM).

16.5.3 The routes or airspace where application of strategic lateral offsets is authorized, and the procedures to be followed by pilots, shall be promulgated in aeronautical information publications (AIPs). In some instances it may be necessary to impose restrictions on the use of strategic lateral offsets, e.g. where their application may be inappropriate for reasons related to obstacle clearance. Route conformance monitoring systems shall account for the application of SLOP.

16.5.4 The decision to apply a strategic lateral offset shall be the responsibility of the flight crew. The flight crew shall only apply strategic lateral offsets in airspace where such offsets have been authorized by the appropriate ATS authority and when the aircraft is equipped with automatic offset tracking capability.

Note 1.— Pilots may contact other aircraft on the inter-pilot air-to-air frequency 123.45 MHz to coordinate offsets.

Note 2.— The strategic lateral offset procedure has been designed to include offsets to mitigate the effects of wake turbulence of preceding aircraft. If wake turbulence needs to be avoided, an offset to the right within the limits specified in 16.5.2 may be used.

Note 3.— Pilots are not required to inform ATC that a strategic lateral offset is being applied.

2.2 WHY AIRCRAFT SHOULD OFFSET

2.2.1 The extreme accuracy of the global navigation satellite system (GNSS) and today's altimeter systems can result in high collision risk when an error occurs in the system. This may for example happen when an aircraft is flying at a level that is not expected by ATC. Applying an offset to the right of track significantly reduces the collision risk between aircraft on the same or opposite direction tracks in such circumstances because the aircraft obtains lateral spacing from nearby aircraft that are immediately above and below.

2.2.2 An example is a mid-air collision where a Boeing 737 collided head on with an Embraer legacy business jet. Both aircraft were assigned flight level 370, the Embraer transponder was not operating and neither aircraft received a traffic alert and collision avoidance system (TCAS) alert. All 154 passengers and crew aboard the Boeing 737 were killed. An offset to the right by one or both aircraft would have prevented this accident.

2.2.3 The higher the usage of SLOP the greater the resulting collision risk reduction. But even a small uptake of SLOP, has a significant effect. For example, a single offsetting aircraft flying the North Atlantic in a direction opposite to the main traffic flow may be passing a considerable number of opposite direction aircraft. This single aircraft applying SLOP provides a reduced risk, not only for itself, but also for all the other encountered aircraft, even though they were not participating in any form of offset.

2.3 WHERE AIRCRAFT SHOULD OFFSET

2.3.1 As stated in the PANS-ATM, Section 16.5, a flight crew should only apply SLOP if the following conditions are satisfied:

a) the appropriate ATS authority has authorized the application of SLOP in the airspace concerned and promulgated in aeronautical information publications (AIPs);

b) the aircraft is equipped with automatic offset tracking capability; and

c) if the maximum allowed lateral offset is 0.5 NM, then only aircraft capable of offsetting in a fraction of a mile should apply SLOP.

2.3.2 When operating in airspace where SLOP has been authorized, the decision to apply SLOP is the responsibility of the flight crew.

Note.— Automatic offset tracking capability is a flight management system (FMS) capability of creating a route parallel to the active route and intercepting and flying that route when executed by the pilot.

2.4 WHEN AIRCRAFT SHOULD OFFSET

2.4.1 Due to the positive effect on collision risk, flight crew of suitably equipped aircraft should apply SLOP as a standard operating procedure in all airspace where the procedure has been approved and promulgated by the appropriate authority. The offset should be applied from the time the aircraft reaches its cruising level until top of descent.

2.4.2 Aircraft not flying a published route or track could also apply SLOP. Even though such aircraft normally present a smaller overlap risk due to the random nature of such operations, the offset would not have any negative impact, but would rather have a positive impact in case the flight experienced proximate same direction or opposite direction random route aircraft.

2.5 HOW AIRCRAFT SHOULD OFFSET

2.5.1 The effect of SLOP is maximized if the traffic is evenly distributed among the available lateral offset options. Therefore pilots should choose a lateral offset position in accordance with the following:

a) if flying in airspace where a maximum of 0.9 km (0.5 NM) offset is approved:

   1) randomly choose an offset position of 0.2 km (0.1 NM), 0.4 km (0.2 NM), 0.6 km (0.3 NM), 0.7 km (0.4 NM) or 0.9 km (0.5 NM) right of track;

b) if flying in airspace where a maximum of 3.7 km (2 NM) offset is approved:

   1) if the aircraft is equipped with a capability to offset in tenths of a nautical mile then randomly choose an offset position of 0.2 km (0.1 NM) or more up to 3.7 km (2 NM) right of track; and

   2) if the aircraft is equipped with a capability to offset only in whole nautical miles then randomly choose centreline or an offset position of 1.9 km (1 NM) or 3.7 km (2 NM) right of track.

2.5.2 If pilots are aware of other aircraft immediately above or below they should use whatever means are available (e.g. TCAS, visual acquisition, or communications with other aircraft on an inter-pilot air-to-air frequency) to determine the best offset position.

2.5.3 If there is a need to apply offsets to mitigate the effect of wake turbulence, then the crew should choose the most suitable offset positions of those specified above. An aircraft overtaking another aircraft should, if capable, offset within the confines specified above so as to create the least amount of wake turbulence for the aircraft being overtaken.

2.5.4 Voice position reports should be based on the waypoints of the current ATC clearance and not the offset positions.

2.5.5 There is no ATC clearance required for the application of SLOP and it is not necessary to inform ATC.

Offsets to the left should NOT be made under any circumstances unless under clearance from ATC.

2.6 CONSIDERATIONS FOR THE APPROPRIATE AUTHORITY

2.6.1 Civil aviation authorities are urged to authorize SLOP as a collision risk mitigation measure wherever it is possible. The following is recommended to be taken into account when authorizing the use of SLOP in a particular airspace:

a) implementation in coordination between all States involved will improve harmonization and clarity related to area of implementation across FIRs. Fragmented areas of SLOP implementation could create pilot confusion as to whether the procedure is authorized;

b) SLOP is to be authorized only between top of climb and top of descent;

c) in airspace where the lateral separation minima or route spacing is 55.5 km (30 NM) or more the maximum allowable offset value is 3.7 km (2 NM);

d) in airspace where the lateral separation minima or route spacing is 11.1 km (6 NM) or more and less than 55.5 km (30 NM), the maximum allowable offset value is 0.9 km (0.5 NM);

e) SLOP is not to be applicable in airspace where the lateral separation minima or route spacing is less than 11.1 km (6 NM);

f) the routes or airspace where application of SLOP is authorized, and the procedures to be followed by pilots, are to be published in aeronautical information publications (AIPs);

g) air traffic controllers need to be made aware of the airspace where SLOP is authorized;

h) in some instances it may be necessary to impose restrictions on the use of SLOP, e.g. where their application may be inappropriate for reasons related to obstacle clearance;

i) route adherence monitoring systems should account for the application of SLOP; and

j) the location of any prohibited, restricted or danger areas must be taken into account before SLOP are authorized.

Chapter 3

SASP SAFETY ASSESSMENT

3.1 INTRODUCTION

3.1.1 This chapter summarizes the safety assessment performed by SASP to determine under which circumstances the application of SLOP would be safe. The methodology is explained below, as is the rationale behind its use and the conclusions drawn from it.

3.2 SCOPE OF SASP SAFETY ASSESSMENT

3.2.1 In the context of the scope of the safety assessment, it is useful and necessary to distinguish between safety assessments undertaken by States for purposes of implementation at 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 can be seen that because the local operating environment into which SLOP 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-focused assessment. It should be noted that a local implementation assessment may not necessarily require a regional assessment but may be initiated by an ANSP on a case-by-case basis.

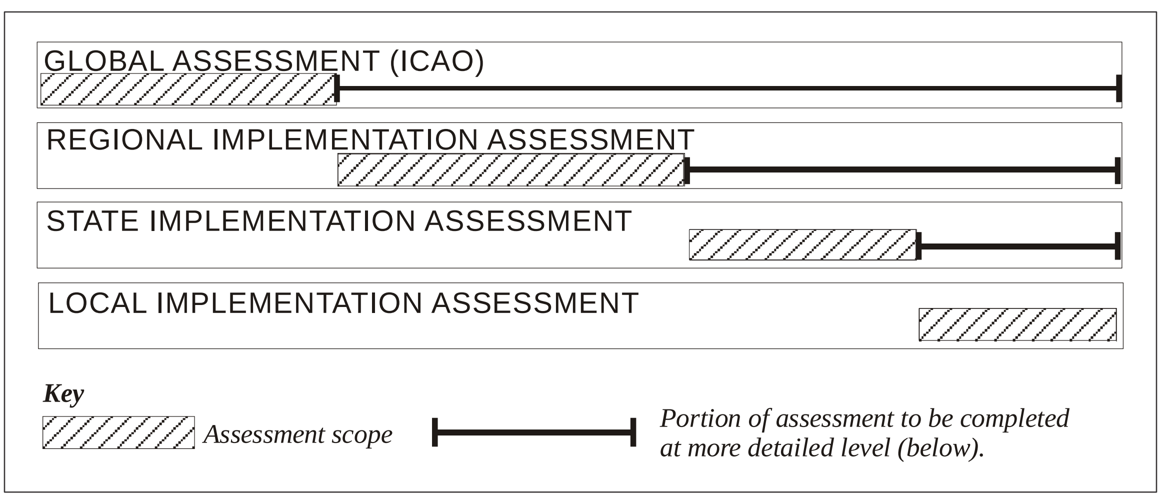

Figure 3-1. Safety assessment scope

3.2.3 SASP's assessment is based on a number of assumed characteristics related to either the airspace environment or aircraft performance (see 3.3.11). These characteristics may not necessarily be the same as those relevant to any particular regional, State or local implementation.

3.2.4 In undertaking an implementation supporting safety assessment it should begin with a review of SASP's global assessment taking particular note of the assumed characteristics used in that assessment. Where these characteristics are the same or more stringent than those within the airspace being considered, then the analysis only needs to focus on undertaking an assessment of issues related specifically to implementation.

3.3 OBJECTIVES AND DEVELOPMENT OF SASP SAFETY ASSESSMENTS

3.3.1 Strategic lateral offsets as described in Chapter 2 have a mitigating effect on vertical and longitudinal collision risk. However, depending on the directions of flow, they may lead to some increase in lateral collision risk, both for non-intersecting (parallel) tracks and intersecting tracks.

3.3.2 The objective of the SASP safety assessment in support of the use of SLOP was to determine whether the increases, if any, in lateral collision risk due to the use of SLOP would be tolerable.

3.3.3 Early work on lateral offsets examined the anticipated effects of using several possible procedures, principally in systems of parallel routes. Different procedures offered different reductions in vertical and longitudinal risk, and – depending in some cases on the route configuration or method of application – either increases or decreases in lateral risk. Studies by SASP and its predecessor, the RGCSP, also considered different levels of aircraft equipage with GNSS, different levels of aircraft equipage with offset capability, different navigational capabilities of the non-GNSS part of the fleet, and different probabilities that aircraft equipped to apply offsets would actually do so. Details are given in the summaries provided in section 3.4.

3.3.4 Later work on lateral offsets also examined their possible effect on intersecting-tracks collision risk. Apart from the traditional lateral separation minima for VHF omnidirectional radio range (VOR), and non-directional radio beacon (NDB), dead reckoning, and area navigation (RNAV) operations, the PANS-ATM provided a method of applying lateral separation for "RNAV operations (where RNP is specified) on intersecting tracks or air traffic services (ATS) routes" based on the concept of a defined area of conflict around an intersection (Ref. 53). This method of applying lateral separation was superseded by an alternative method of applying lateral separation on intersecting tracks based on a "protected" region of airspace on either side of the track of a reference aircraft (ref. 55). The reason for the replacement was that the SASP saw several operational advantages of the alternative method over the area of conflict method. SLOP risk assessments have been performed for both methods of applying intersecting-tracks lateral separation and are included below. Details of the lateral offset work for both the area of conflict method and the protected region method are provided in 3.5.

3.3.5 In the context of the safety assessment of existing separation minima combined with SLOP, a distinction is made between collision risk due to navigation performance and risk due to other hazards.

3.3.6 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: Dependent on the case, the expression "atypical navigation performance" may be used in case of navigation system failure or degradation, and/or operational error.

3.3.7 Typical and atypical navigation performance falls 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.

3.3.8 The assessment of the collision risk due to navigation performance complies with the guidance from the *Manual on Airspace Planning Methodology for the Determination of Separation Minima* (Doc 9689) concerning the "Evaluation of system risk against a threshold" method.

3.3.9 Existing lateral separation minima for parallel tracks and intersecting tracks are considered to be "safe" when:

a) the 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 $5x10^{-9}$ fatal aircraft accidents per flight hour; and

b) the risk due to all other hazards not considered in the modelling is "negligible".

3.3.10 The use of lateral offsets may increase the lateral collision risk for an existing safe separation minimum, even to a level greater than the TLS. It is necessary, therefore, to define additional criteria to judge whether such increases are tolerable. Ideally, such criteria should also take into account the corresponding reductions in the vertical and longitudinal collision risks. These additional criteria will be presented as a part of each individual assessment in Section 3.4 and 3.5 below.

3.3.11 Several assumptions were made during the safety assessment by SASP:

a) an aircraft employing a lateral offset would be equipped with GNSS for positioning and a FMS capable of offsetting laterally from the aircraft's cleared routing;

b) internationally applied collision-risk methodology is appropriate to assess the increase or decrease in collision risk in the various dimensions when the offset procedure is applied; and

c) a significant reduction in collision risk in one dimension (for example, the vertical) attributable to application of the procedure is desirable even if application of the procedure leads to a small increase in collision risk in another dimension (for example, the lateral).

3.3.12 A significant enabler for the implementation of SLOP is the development and equipping of aircraft with a flight management system capable of providing automatic offsets in either one NM increments or, for some modern aircraft, in increments of tenths of a nautical mile. A full level of equipage, while significant as an end-state goal, is not required, as any aircraft applying SLOP adds to the safety of the system.

3.4 SAFETY ASSESSMENT FOR SLOP AND NON-INTERSECTING TRACKS

RGCSP-WG/B Meeting, October 1998

3.4.1 The RGCSP began quantitative work on lateral-offset procedures at its meeting in October 1998. The panel conducted its business in two working-group meetings: that of WG/A, which concentrated on matters of horizontal separation, and that of WG/B, which concentrated on vertical separation. The use of lateral offsets was seen as a means of mitigating increases in risk arising from two trends: 1) the implementation of RVSM above FL290 in airspaces around the world; and 2) the increasing use of the highly accurate GNSS. The panel recognized that if two aircraft, assigned to the same route, lose their planned vertical separation, they avoid a collision only if they have random longitudinal separation or random lateral separation. The increased use of GNSS drastically reduces the probability that two such aircraft will have random lateral separation. Thus the use of lateral offsets was seen as a means of restoring some lateral dispersion (about the route centre line) to the traffic assigned to any particular route. Since the implementation of RVSM provided the impetus for the use of lateral offsets, the topic was considered in the meeting of WG/B.

3.4.2 The October 1998 meeting of RGCSP WG/B, suggested a plan for random lateral offsets (ref. 3)[1]. It was first shown that the probability of a collision, in the event of a loss of planned vertical separation, varies directly with the lateral overlap probability of the aircraft involved in the encounter. Thus the benefit of implementing an offset scheme can be assessed by the extent to which it reduces the lateral overlap probability of a pair of aircraft assigned to the same route. It was later shown that it is technically feasible to use random offsets limited by any finite distance. A typical scientific calculator, costing very little, includes a random number generator. By generating a random number between 0 and 1, and then using the calculator to apply a simple linear transformation, a pilot could easily determine the direction and extent of his random offset. Since the random numbers are uniformly distributed between 0 and 1, the resulting offsets would also be uniformly distributed on some chosen interval.

3.4.3 It was assumed that a typical aeroplane's lateral distance from its intended path, at any arbitrarily chosen moment, is a normally distributed random variable having mean 0 and standard deviation equal to the aeroplane's required navigation performance (RNP) value divided by 1.96 (this assumption was based on the original definition of RNP values as distances that provide 95 per cent containment). An aeroplane's signed distance from its route centre line is the algebraic sum of its intended lateral offset and its deviation from its intended path. The difference between two such sums represents the lateral distance between the centres of two aircraft assigned to a given path. The meeting provided a formula for the probability density function of this difference. When the absolute value of the difference is less than the wingspan of an aeroplane, the two aircraft have laterally overlapping positions.

3.4.4 The formula for the density function was used to produce three graphs. In one of them aircraft were assumed to meet RNP 10; in another they were assumed to meet RNP 4; and in the third they were assumed to meet RNP 1. The horizontal axis of each graph showed values of the maximum allowable offset distance, ranging from 0.9 km (0.5 NM) to 5.5 km (3 NM). The vertical axis showed (for each point on the graph) the ratio of the lateral overlap probability when offsets are used, to the lateral overlap probability when offsets are not used. Thus each graph showed (for one of the three RNP values) the extent to which the

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1 The reference material at the end of this circular provides a (nearly) complete, chronologically ordered, bibliography of all the material considered by SASP in developing the procedure and safety assessment detailed in Circular 331. Only a limited number of documents are explicitly referenced in sections 3.4 and 3.5.

use of offsets would reduce lateral overlap probability. In each graph, the reduction in overlap probability varied directly with the maximum allowable offset distance, so that the greatest reduction was achieved when the maximum offset could be as great as 5.5 km (3 NM).

3.4.5 For aircraft that met RNP 10, the maximum reduction in lateral overlap probability was only slightly greater than 5 per cent. This is because these aircraft already exhibit a wide dispersion about the route centre line; and so the use of offsets would yield only a slight increase in dispersion, and a slight decrease in lateral overlap probability. Aircraft that met the classical definition of RNP 4 (i.e. 95 per cent containment within 7.4 km (4 NM) of the intended path) could achieve a reduction of 25 per cent in lateral overlap probability if the maximum allowable offset distance were 5.5 km (3 NM). Aircraft that met the classical definition of RNP 1 would benefit the most from the offset scheme, as their lateral overlap probabilities would decrease by more than 70 per cent if they used uniformly distributed offsets with a maximum distance of 5.5 km (3 NM).

3.4.6 RGCSP WG/B recognized that the offset capabilities available in much of the commercial fleet allow aircraft to fly on paths offset from a programmed route by whole numbers (i.e., integer values) of nautical miles. Though it would still be technically possible to apply uniformly distributed offsets – e.g. by programming offset way-points into a flight management system – the working group found the use of uniformly distributed offsets to be impractical. Until 2009, when SASP began technical studies of "micro-offsets", all further RGCSP and SASP documents dealing with offsets assumed that they would be specified in integer numbers of nautical miles.

RGCSP-WG/A Meeting, May 1999

3.4.7 The RGCSP recognized that the use of lateral offsets could give rise to increases in lateral risk. Before endorsing any particular scheme for applying offsets, the panel asked its (newly created) mathematicians' subgroup to examine the change in lateral risk that might result from the use of offsets of 1.9 km (1 NM), 3.7 km (2 NM) or 5.5 km (3 NM). Documents for the meeting, examined several scenarios specified by the panel, in order to estimate the changes in lateral risk caused by the use of offsets (ref. 6).

3.4.8 The first three scenarios considered by the meeting assumed a pair of parallel routes, spaced 50 NM apart, carrying same-direction traffic. In one scenario the aircraft satisfied RNP 10; in another they satisfied RNP 4; and in the third they satisfied RNP 1. Aircraft assigned to a pair of parallel routes decrease their lateral risk by using offsets that increase their intended lateral separation. Therefore all cases in the first three scenarios in which aircraft offsets increase, their intended separation were ignored. To avoid unnecessary complications, it examined only those (hypothetical) cases in which the offsets are of the same magnitude, and move the aircraft toward each other. To limit the number of cases under consideration, the paper showed computations only for pairs of aircraft that meet the same RNP level. All computations assumed that aircraft lateral deviations from their intended paths (at any arbitrarily chosen moment) are random signed distances that can be described by a double exponential (DDE) distribution. The parameter of the DDE's "core distribution" was derived from the RNP value of the aircraft being considered; the parameter of the DDE's "tail distribution" was (conservatively) taken to be the spacing between the routes; and the "mixing parameter" was derived from studies of North Atlantic traffic in the mid-1990s.

3.4.9 If RNP 1 aircraft on both routes apply offsets of 1.9 km (1 NM), 3.7 km (2 NM) or 5.5 km (3 NM) toward each other – thereby reducing their intended lateral separation to 48, 46 or 44 NM – the increase in lateral overlap probability is relatively small. Each 2 NM decrease of intended separation increases the lateral overlap probability (and lateral risk) by approximately 4 per cent. The same result holds if the aircraft meet RNP 4. However, when the aircraft meet RNP 10, the increases in risk are far greater.

Each decrease of 2 NM in intended lateral separation increases lateral risk by an amount between 30 and 50 per cent. The effect of a 6 NM reduction in intended separation, from 93 km (50 NM) to 81.5 km (44 NM), is to increase lateral risk by 172 per cent.

3.4.10 The next three scenarios considered by the meeting again assumed a pair of parallel routes spaced 93 km (50 NM) apart, and aircraft that satisfied RNP 1, RNP 4 and RNP 10. The routes were unidirectional, but their flows were in opposite directions. Therefore, the computed values of absolute risk were approximately an order of magnitude greater (for the same level of occupancy) than those of the first three scenarios. Since lateral overlap probabilities did not depend on the directions of traffic flow, the percentage changes in risk for these scenarios were identical to those of the first three scenarios.

3.4.11 The seventh scenario considered had four unidirectional parallel routes, all spaced 93 km (50 NM) apart, and all carrying RNP 10 aircraft in the same direction. Since each of the two inner routes was adjacent to the other, and was also adjacent to one of the two outer routes, an offset executed by an aeroplane assigned to an inner route increased its intended lateral separation from one of the adjacent routes, but decreased its intended lateral separation from the other. Moreover, the risk computations depended on the distribution of traffic over the routes and flight levels in the system, and could, therefore, become extremely complex. Documentation for the meeting also provided, by examples, that if the traffic is appropriately distributed, it is even possible for the use of offsets to cause a decrease in the estimated rate of accidents due to the loss of planned lateral separation. Such decreases could occur, for example, if aircraft assigned to heavily loaded inner routes offset away from each other, toward lightly loaded outer routes.

3.4.12 The eighth, ninth and tenth scenarios also had four unidirectional parallel routes, spaced 93 km (50 NM) apart, carrying RNP 10 aircraft; but some pairs of adjacent routes had opposite-direction flows. In the eighth scenario, each pair of adjacent routes had traffic moving in opposite directions. In the ninth scenario, the two inner routes carried same-direction traffic, while each outer route carried traffic in the direction opposite that of the inner routes. In the tenth scenario the two inner routes carried traffic moving in opposite directions, and each outer route carried traffic moving in the same direction as its adjacent inner route.

3.4.13 Since all pairs of adjacent routes in the eighth scenario had opposite-direction traffic, the risk estimates were analogous to those for the seventh scenario, with the only difference being the use, in the Reich model, of the kinematic factor $k(opp)$ for opposite-direction traffic, rather than $k(same)$, the analogous factor for same-direction traffic. Since $k(opp)$ is approximately an order of magnitude greater than $k(same)$, the absolute risk estimates for the eighth scenario were an order of magnitude greater than those for the seventh scenario; but the percentage changes in risk caused by the use of lateral offsets were identical.

3.4.14 The ninth and tenth scenarios again offered opportunities to show, by example, that the use of lateral offsets has the potential to actually reduce lateral risk. The basic strategy for doing so is to apply offsets that increase the intended lateral separation between aircraft assigned to pairs of opposite-direction routes, while decreasing the intended lateral separation between aircraft assigned to pairs of same-direction routes. (Though the examples were theoretically interesting, it was noted that they might not be fully realistic, in that the occupancy values used for opposite-direction traffic were the same as those used for same-direction traffic. In practice, the same spacing would be used for same-direction route pairs and opposite-direction route pairs only if the opposite-direction occupancies were quite low.)

RGCSP-WG/WHL Meeting, November 1999

3.4.15 After the March 1997 implementation of a reduced vertical separation minimum (RVSM) of

300 m (1 000 ft) in North Atlantic airspace, many pilots noticed an increased incidence of encounters with wake turbulence generated by aircraft flying above them and ahead of them. A notice to airmen (NOTAM) issued in response to this observation, permitted lateral offsets of 3.7 km (2 NM), to the left or right of centre line. The RGCSP then looked into the effect of these lateral offsets on the rate of collisions due to the loss of planned lateral separation.

3.4.16 In November 1999 the RGCSP met as a working group of the whole. Documentation for the meeting estimated the effect on lateral risk of the use of 3.7 km (2 NM) offsets (ref. 6). Its method was similar to that of the May 1999 meeting (ref. 5); however, it introduced notation that remained useful for many other papers on the effects of applying lateral offsets. In particular, it stated the probability of lateral overlap (at an arbitrarily chosen moment) as a sum of products, each having two factors: 1) the (conditional) probability of overlap, given that the intended separation between a pair of aircraft has some particular value; and 2) the probability that the intended separation has that particular value. The sum was taken over all possible values of intended separation.

3.4.17 The route spacing for all the computations was 93 km (50 NM). The possible values of intended separation were, therefore, 85.2 km (46 NM), 88.9 km (48 NM), 93 km (50 NM), 96.3 km (52 NM) and 100 km (54 NM).

3.4.18 The meeting documentation considered six hypothetical values of p, the probability that an aircraft is executing an offset: 0.01, 0.1, 0.2, 0.3, 0.4, and 0.5. For each of those values, and for occupancy values ranging from 0.1 to 2.0, it plotted the rate of accidents for a fleet of RNP 10 aircraft, and for a fleet of RNP 4 aircraft. For the RNP 10 aircraft, each increase of 0.1 in the value of p led to an increase of approximately 1.25 per cent in the estimated accident rate (at each value of occupancy). The total increase in accident rate, as p increased from 0.01 to 0.5, was 6.23 per cent.

3.4.19 For the RNP 4 aircraft, the increase in accident rate caused by each 0.1 increase in p, was approximately 0.016 per cent; and the total increase, from p = 0.01 to p = 0.5, was 0.078 per cent, a negligibly small change.

SASP-WG/A/2 Meeting, November 2001

3.4.20 The RGCSP held its last panel meeting, RGCSP/10, in the spring of 2000; its last working group meeting was held in November of that same year. Thereafter its name changed to SASP; but it continued to meet twice per year.

3.4.21 Documentation for the SASP-WG/A meeting, considered four different plans for dispersing aircraft about the centrelines of their routes (ref. 8):

a) Plan 1 *required* each aeroplane with offset capability to fly along one of four available offset paths: 1.9 km (1 NM) or 3.7 km (2 NM) to the left or right of the centre line;

b) Plan 2 *required* each aeroplane with offset capability to fly on one of two offset paths: 1.9 km (1 NM) to the left of the centre line, or 3.7 km (2 NM) to the right of the centre line;

c) Plan 3 *allowed* each aeroplane with offset capability to fly along the centre line or along either of two available offset paths: 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the centre line; and

d) Plan 4 *required* each aeroplane with offset capability to fly on one of two available offset paths: 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the centre line.

3.4.22 Each of the four plans could be applied to a unidirectional route or a bidirectional route. Therefore, a pair of aircraft assigned to the same route might be flying in the same direction or in opposite directions. The four offset plans and the two directional possibilities suggested a need for eight sets of computations; but the symmetry of plan 1 yields the same formulas for same-direction pairs as for opposite-direction pairs, and thus documentation actually needed to provide results for only seven sets of computations.

3.4.23 The meeting recognized four equipage classes for individual flights. A flight's equipage class depends on whether or not it uses GNSS to navigate, and on whether or not it's equipped to automatically apply lateral offsets. The paper also considered three navigational classes of *pairs* of randomly selected aircraft: pairs whose members both navigate by GNSS; pairs in which one member uses GNSS while the other does not; and pairs in which neither member uses GNSS. The probability that two randomly selected aircraft are in lateral overlap (at the moment when they are selected) was expressed as a sum of products, each having two factors: 1) the conditional probability of overlap, given that the pair is in a particular navigational class, and has a particular intended separation; and 2) the probability that a pair of randomly chosen aircraft is in that navigational class and has that intended separation. The sum was taken over all three navigational classes and all possible values of intended separation (the possible values of intended separation depend on the offset plan being considered, and on whether the chosen aircraft are flying in the same direction or in opposite directions). Computing the probability, needs to be done carefully for a pair of randomly chosen aircraft, belonging to a particular navigation class and that have a particular intended separation. The meeting documentation provided several examples to illustrate a method of deriving formulas for these probabilities; seven appendices provided all of the necessary formulas.

3.4.24 The paper assumed that the lateral deviations of non-GNSS aircraft followed a double exponential distribution, with mean equal to 0 and shape parameter equal to 10/[-ln(0.05]. The lateral deviations of GNSS aircraft were assumed to follow a double exponential distribution with mean 0 and shape parameter 0.15/[-ln(0.05)]. That is, the non-GNSS aircraft were viewed as navigating in accordance with the 95 per cent lateral containment definition of RNP 10, while GNSS aircraft were assumed to exhibit 95 per cent lateral containment within 0.28 km (0.15 NM) of their intended paths. Using formulas already developed by the RGCSP, computed the conditional probability of lateral overlap for each given pair of navigational class and intended separation. As was noted above, the (unconditional) probability of lateral overlap was computed as a sum, each of whose terms was a product of two factors: 1) the conditional probability of lateral overlap, given that a randomly chosen pair of aircraft was in a given navigational class, and had a given intended separation; and 2) the probability that a randomly chosen pair of aircraft was in the given navigational class and had the intended separation.

3.4.25 Documentation for the meeting also computed seven tables of (unconditional) lateral overlap probabilities, each one using a set of formulas from one of the seven appendices. In the absence of data that might indicate the distribution of flights by equipage class (in some particular airspace), the working paper assumed that equipage with GNSS and equipage with offset capability were independent. Thus, for example, the probability that a randomly chosen aeroplane uses GNSS and has offset capability was taken to be the product of the fraction of flights that use GNSS and the fraction of flights that have offset capability.

3.4.26 The computations assumed five hypothetical levels of equipage for lateral offsets, and five hypothetical levels of equipage with GNSS (the equipage levels for offsets were 75, 80, 85, 90, and 95 per cent; the equipage levels for GNSS were 35, 50, 65, 80 and 95 per cent). Each of the seven tables of results (and its accompanying graph) showed 25 lateral overlap probabilities, each corresponding to one of the twenty-five pairs of hypothetical equipage levels.

3.4.27 The results for same-direction traffic showed that for each offset plan, and for each level of equipage for the application of offsets, lateral overlap probability increases uniformly with increasing GNSS equipage. Though the level of equipage for the application of offsets was seen to be significant, changes in that level did not produce large changes in lateral overlap probability at any particular value of GNSS equipage. The offset plan that yielded the smallest (best) values of lateral overlap probability at large values of GNSS equipage, was plan 1 – probably because it offered five possible paths at each flight level (the centre line and four offset paths) while the other plans offered only three – the centreline and two offset paths.

3.4.28 The uniform increase in lateral overlap probability at each level of equipage for the application of offsets was also seen for opposite-direction traffic operating with offset plan 1 and for opposite-direction traffic operating with offset plan 3. However, offset plans 2 and 4 offered an interesting result: While the uniform increase in lateral overlap probability still prevailed at the three lowest levels of equipage for the application of offsets (viz. 75, 80 and 85 per cent), at the two highest levels of equipage (90 and 95 per cent) the lateral overlap probability *decreased* with increasing use of GNSS. This result was seen as a consequence of the detailed provisions of the offset plans. Much of the lateral overlap probability was due to GNSS-equipped aircraft that aim to fly along the same path (though perhaps at different flight levels). Under all four plans, a pair of GNSS-equipped aircraft without offset capability is required to use the centreline. Under plan 1 a pair of GNSS-equipped aircraft *with* offset capability still has a 25 per cent chance of having the same intended offset path for both of its members. Under plan 3, aircraft with offset capability retain the option of flying along the centre line; and thus, even as the equipage for offsets increases, the centre line continues to have a high probability of being the intended path of two GNSS-equipped aircraft. Under plans 2 and 4 all aircraft that have offset capability are *required* to fly on offset paths; and under those plans a pair of opposite-direction aircraft with offset capability *cannot* have the same intended path.

SASP-WG/WHL/1 Meeting, May 2002

3.4.29 The first meeting of the SASP working group of the whole took place in May 2002. Several months earlier, in November 2001, an offset procedure – “plan 3” of the meeting in November 2001 (ref. 8) – had been implemented on a trial basis in the West Atlantic Route System (WATRS). Plan 3 allowed each aeroplane with offset capability to fly along its route’s centre line or along either of two available offset paths: 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the centre line. The working group recognized that an offset policy was likely to cause some increase in lateral overlap probability and lateral risk, for aircraft assigned to adjacent parallel routes; but it hoped that (at least in most cases) the increase in lateral risk would be small, and could be accepted in order to obtain a far greater decrease in vertical risk.

3.4.30 The meeting hypothesized a pair of unidirectional routes, parallel to each other (ref. 9). It considered two aircraft, one assigned to each of the routes (both aircraft were assumed to be assigned to the same flight level). The meeting considered three different configurations of the routes carrying:

a) same-direction traffic;

b) opposite-direction traffic, and each aeroplane had the other route on its left; and

c) opposite-direction traffic and each aeroplane had the other route on its right.

3.4.31 It was important to distinguish between the two situations involving opposite-direction traffic, because the offsets carried out under plan 3 were necessarily to the right. When aircraft had opposite-direction traffic on the left, their offsets (to the right) increased their intended distance from the opposing traffic, and decreased their probability of being in lateral overlap. When they had opposite-direction traffic on the right, their offsets decreased their intended distance from the opposing traffic, and increased their probability of being in lateral overlap.

3.4.32 The general method of analysis used (ref. 9) was similar to that of documentation issued in the November 2001 SASP meeting (ref. 8). A randomly chosen pair of aircraft (one assigned to each route) was assumed to belong to one of three navigational classes: 1) the class of pairs whose members both navigate by GNSS; 2) the class of pairs that have one aeroplane navigating by GNSS, and one navigating by some other means; and 3) the class of pairs whose members both navigate by means other than GNSS. The probability of overlap for the chosen pair is computed as a sum of products, with each product having two factors: 1) the conditional probability of overlap, given that the pair of aircraft is in a particular navigational class, and has a particular intended separation; and 2) the probability that the pair is in that navigational class and has that intended separation. The sum is taken over all three navigational classes and all possible values of intended separation. As in documentation for the meeting, the possible values of intended separation depend on the configuration of the routes; but under plan 3, each configuration gives rise to five possible values of intended separation. Thus, for each of the three route configurations, there are 15 formulas for the probability that a randomly chosen pair of aircraft belongs to a particular navigational class and has a particular intended separation. Detailed derivations were provided for some of these 45 formulas, and, for the sake of completeness, listed all of them.

3.4.33 Documentation for the meeting treated aircraft lateral deviations from their intended paths as signed random distances having double-double-exponential (DDE) distributions. The spread parameter of the "core density" of each DDE density function was taken to be the RNP value of the relevant aeroplane divided by $-\ln(0.05)$. Non-GNSS aircraft were assumed to meet RNP 10; and aircraft that navigate by GNSS were assumed to have 95 per cent containment of their lateral errors within 0.28 km (0.15 NM). In each computation of lateral overlap probabilities, the values of the spread parameters of the "tail densities" were conservatively taken to equal the spacing between the routes (as that value approximately maximizes the overlap probability). For each hypothesized configuration of the routes, the computation of lateral overlap probability was done for a range of values of the DDE mixing parameter α. For RNP 10 aircraft the values extended from 10^{-6} to 10^{-3}. For GNSS aircraft, which were assumed to be better equipped, and somewhat less prone to committing atypical navigation errors, the value of the mixing parameter in each computation was taken to be 80 per cent of the value used for RNP 10 aircraft.

3.4.34 The first computation of the effect of using offsets involved a pair of same-direction routes with 93 km (50 NM) spacing, and a fleet that had mixed equipage. In the absence of empirical data, it simply adopted illustrative values for the probability that a randomly chosen aeroplane would be in one of the four capability classes:

a) P (the chosen aeroplane has neither automatic offset capability nor GNSS) = 0.1625;

b) P (the chosen aeroplane does not have automatic offset capability, but does have GNSS) = 0.0875;

c) P (the chosen aeroplane has automatic offset capability, but does not have GNSS) = 0.4875; and

d) P(the chosen aeroplane has both automatic offset capability and GNSS) = 0.2625.

3.4.35 Likewise, the probabilities that aircraft fly on the centre line, or on one of the offset paths, were not based on empirical evidence, but were simply taken to have reasonable illustrative values:

a) P(the chosen aeroplane aims to fly on the centre line) = 0.6;

b) P(the chosen aeroplane aims to fly 1.9 km (1 NM) to the right of the centre line) = 0.15; and

c) P(the chosen aeroplane aims to fly 3.7 km (2 NM) to the right of the centre line) = 0.25 NM.

3.4.36 Lateral overlap probabilities were computed for 16 different values of the DDE mixing parameter for RNP 10 aircraft. The computation was then redone under the assumption that an offset plan was not available, i.e., that P(the chosen aeroplane aims to fly on the centre line) = 1.0. The use of lateral offsets did cause small increases in lateral overlap probability, ranging from well under 1 per cent (at $\alpha = 10^{-3}$) to nearly 6 per cent (at $\alpha = 10^{-6}$). The working group found these increases in lateral risk to be acceptable.

3.4.37 The next computation considered a system of same-direction routes having 55.5 km (30 NM) spacing between adjacent routes, and a fleet whose aircraft all use GNSS and are all capable of applying lateral offsets. Thus P (the chosen aeroplane has both automatic offset capability and GNSS) was set to 1.0; and the probabilities that a randomly chosen aeroplane is in one of the other three capability classes were all set to 0. At all values of α (the rate of atypical errors) the use of lateral offsets caused a negligibly small increase in lateral overlap probability – less than 0.1 per cent.

3.4.38 The meeting considered the possibility that aircraft navigating by inertial reference system (IRS) might obtain approval as RNP 4 aircraft, and qualify to fly on RNP 4 routes. (Later changes to the definition of RNP 4 restricted that classification to aircraft navigating by GNSS; and thus this possibility was never realized.) The meeting presented results for a system of same-direction routes spaced 55.5 km (30 NM) apart, in which all of the aircraft were capable of applying offsets, and 40 per cent of the fleet used GNSS while the other 60 per cent met RNP 4 without using GNSS. For almost all values of α, the use of offsets increased lateral overlap probability by less than 1 per cent.

3.4.39 The next three computations showed results of using offsets on pairs of opposite-direction routes for which aircraft have opposite-direction traffic on the left. Since offsets to the right increase the intended separation between the aircraft of such route pairs, the probability of lateral overlap decreases (as does the rate of collisions due to the loss of planned lateral separation).

3.4.39.1 One computation assumed 93 km (50 NM) spacing with the same distribution of aircraft capabilities and the same distribution of offset usage that had been assumed in the computations for same-direction routes spaced 93 km (50 NM) apart. The reductions in lateral overlap probability ranged from approximately 3 to approximately 26 per cent.

3.4.39.2 The next computation assumed 55.5 km (30 NM) spacing, with all aircraft equipped for both GNSS and offsets. At all values of α the lateral overlap probability decreased approximately 6 per cent.

3.4.39.3 The third computation involving opposite-direction routes that have opposing traffic on the left of each aeroplane, assumed 55.5 km (30 NM) spacing and a fleet fully equipped to apply offsets; 40 per cent of the fleet was assumed to navigate by GNSS, and 60 per cent by a non-GNSS system that meets RNP 4. The decreases in lateral overlap probability, for values of α ranging from 10^{-6} to 10^{-3}, were between 6.65 and 8.25 per cent.

3.4.40 The last three computations showed results of using offsets on pairs of opposite-direction routes for which aircraft have opposite-direction traffic on the right. Since offsets to the right decrease the intended separation between the aircraft of such route pairs, the probability of lateral overlap increases (as does the rate of collisions due to the loss of planned lateral separation).

3.4.40.1 The first of these computations assumed 93 km (50 NM) spacing with the same distribution of aircraft capabilities and the same distribution of offset usage that had been assumed in the computations for same-direction routes spaced 93 km (50 NM) apart. The increases in lateral overlap probability were only a few per cent at $\alpha = 10^{-3}$; but they increased steadily as α decreased, reaching more than 50 per cent at $\alpha = 10^{-6}$.

3.4.40.2 The second computation assumed 55.5 km (30 NM) spacing, with all aircraft equipped for both GNSS and offsets. At all values of α, the lateral overlap probability increased by almost 7 per cent.

3.4.40.3 The third computation involving opposite-direction routes that have opposing traffic on the right of each aeroplane, assumed 55.5 km (30 NM) spacing and a fleet fully equipped to apply offsets. 40 per cent of the fleet was assumed to navigate by GNSS and 60 per cent by a non-GNSS system that meets RNP 4. The increases in lateral overlap probability, for values of α between 2×10^{-5} and 10^{-3}, were approximately 8 per cent. As α decreased from 2×10^{-5} to 10^{-6} lateral overlap probability increased from 8 to approximately 20 per cent.

3.4.41 Computations showed that the use of the "plan 3" offset scheme was not likely to cause significant increases in lateral overlap probability as long as the route system consisted of same-direction routes, or of opposite-direction routes having opposing traffic on the left of each aeroplane. On the other hand, if the system had opposite-direction routes, with opposing traffic on the right of each aeroplane, the use of "plan 3" offsets might lead to significant increases in the rate of collisions due to the loss of planned lateral separation.

SASP-WG/WHL/3 Meeting, May 2003

3.4.42 Documentation for the May 2003 SASP meeting again considered the effects of offsets on the lateral overlap probabilities experienced by aircraft assigned to the same route (ref. 10). There were, however, some differences between the assumptions from the November 2001 SASP meeting (ref. 8) and those of the May 2003 meeting. The meeting examined four proposed offset procedures, two of which included the possibility of using offsets to the left of the route's centre line, and three of which *required* aircraft to apply offsets if they were equipped to do so. The meeting also examined six procedures, one of which was simply a "base case" – useful for comparisons – in which offsets were not permitted. All five of the other procedures involved only offsets to the right. Some of them required GNSS-equipped aircraft to apply offsets; others simply permitted them. The six proposed procedures were:

a) offsets are not permitted. This was a "base case", included in the study in order to show the effect of inaction, i.e., of not adopting any offset procedure;

b) only GNSS-equipped aircraft that have automatic offset capability are allowed to apply offsets, and the offsets must be 1.9 km (1 NM) to the right of the route's centre line. All other aircraft must try to fly along the centre line. This procedure was then being proposed to ICAO for implementation on South Pacific routes;

c) only GNSS-equipped aircraft with automatic offset capability are allowed to apply offsets, but an offset may be 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the route’s centreline. All other aircraft must try to fly along the centre line. This procedure extended procedure 2) by allowing 3.7 km (2 NM) offsets;

d) all aircraft with automatic offset capability are allowed to apply offsets. An offset may be 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the route’s centreline. This was the procedure that had been implemented on a trial basis in the West Atlantic Route System (WATRS), i.e. “plan 3" of documentation from the SASP-WG/A/2 (ref. 8);

e) GNSS-equipped aircraft with automatic offset capability are required to apply offsets, which may be 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the route’s centre line. All other aircraft must try to fly along the centreline. This procedure was included in order to show the effect of eliminating the major source of lateral overlap probability, i.e. the use of the route’s centre line by GNSS-equipped aircraft; and

f) GNSS-equipped aircraft with automatic offset capability are required to apply offsets, which may be 1.9 km (1 NM) or 3.7 km (2 NM) to the right of the route’s centre line. All other aircraft having automatic offset capability are allowed to apply offsets. This procedure extended procedure 5) by allowing non-GNSS-equipped aircraft to apply offsets.

3.4.43 The meeting did not compute lateral overlap probabilities for pairs of aircraft flying in the same direction. Its computations were limited to pairs of opposite-direction flights.

3.4.44 Much of the theoretical development presented in a working paper (ref. 10) was similar to that of other documentation (ref. 8); however, the inclusion of procedures in which the use of offsets was optional, complicated many of the formulas. It provided derivations of general formulas for the probability that a randomly chosen pair of (opposite-direction) flights is in a particular navigation class, and that its members have selected a given pair of offset distances. It also translated these general formulas into specific formulas for each of the six proposed offset procedures.

3.4.45 In the absence of empirical data on the equipage of the aircraft in any particular airspace, and in the absence of data on the extent to which aircraft might be expected to apply lateral offsets, it simply assumed illustrative values (that did not seem unrealistic) for many of its parameters. The fraction of flights equipped with neither offset capability nor GNSS was taken to be 0.05; the fraction equipped with GNSS, but not with offset capability, was taken to be 0; the fraction having offset capability but not GNSS was taken to be 0.65; and the fraction with both offset capability and GNSS was taken to be 0.30. Six parameters were defined for the six probabilities that an aircraft has or does not have GNSS, and applies an offset of 0 NM, 1 NM or 2 NM. Aircraft that do not have offset capability were assumed to use offsets of 0 NM – i.e., to aim to fly along the centre line of the route. Under procedures (5) and (6), which require the use of offsets by offset-capable GNSS-equipped aeroplanes, the probability that such an aircraft aims to fly along the centre line was assumed to be zero. In the most general case – i.e., procedure (4) – the probability of trying to fly along the centre line was taken to be 0.5, the probability of applying a 1 NM offset was taken to be 0.25, and the probability of applying a 2 NM offset was also taken to be 0.25. As in other working papers on the use of lateral offsets, GNSS-equipped aircraft were assumed to have 95 per cent lateral containment distances of 0.15 NM. Non-GNSS-equipped aircraft were assumed to have 95 per cent containment distances of 2 NM, 3 NM, 4 NM, 6 NM, 8 NM, or 10 NM. Lateral overlap probabilities were computed for each of the six procedures, and for each of the six 95 per cent containment distances of the non-GNSS aircraft.

3.4.46 Using offset procedure 2) rather than procedure 1) – which is the base case in which offsets are not permitted – caused significant decreases in lateral overlap probability, typically between 50 per cent (for 95 per cent containment distances of 3.7 or 5.5 km (2 or 3 NM) and 60 per cent (for 95 per cent containment distances of 8 or 10 NM). The use of procedure 3) yielded small improvements over the use of procedure 2) – typically between 1.5 and 3 per cent. Procedure 4) further reduced lateral overlap probabilities, with the reductions varying between 5.8 per cent (when the non-GNSS aircraft meet RNP 10) and 34.4 per cent (when the non-GNSS aircraft have a 95 per cent containment distance of 3.7 km (2 NM). Procedure 5 reduced overlap probabilities (from those of procedure 4) by amounts ranging from 25.5 per cent for the most accurately navigating non-GNSS aircraft, to 59.1 per cent for the least accurately navigating. Procedure 6 improved on the results of procedure 5 by again reducing lateral overlap probability: by 12.9 per cent for non-GNSS aircraft that meet RNP 10 to 48.6 per cent for non-GNSS aircraft that have 95 per cent lateral containment of 3.7 km (2 NM). The total reduction in lateral overlap probability, from procedure 1 to procedure 6, exceeded 85 per cent for all values of the 95 per cent lateral containment distance of the non-GNSS aircraft using the route.

The result of discussions on the use of offsets in increments of 1 nautical mile

3.4.47 The SASP recommended and ICAO adopted the lateral offset procedure that had been implemented on a trial basis in the West Atlantic Route System (WATRS). The November 2001 SASP meeting (ref. 8), it was “plan 3”; in documentation of the May 2002 meeting (ref. 9), it was the only offset procedure considered; and in the May 2003 meeting (ref. 10), it was “procedure 4”.) The procedure differs from several others that had been considered, in that its use of (non-zero) offsets is entirely optional, and is available to any aeroplane equipped to apply automatic offsets, whether or not that aeroplane navigates by GNSS.

3.4.48 The lateral-offset procedure adopted by ICAO became known as SLOP. It was to be used only in oceanic or remote airspaces, where route spacings were generally large enough that any increase in lateral risk due to the use of offsets was expected to be far less than the accompanying decrease in vertical (and longitudinal) risk.

SASP-WG/WHL/16 Meeting, November 2009

3.4.49 Although route spacing in continental airspace was typically too small for the use of SLOP, the SASP eventually became aware of offset capabilities built into some new models of aircraft, which permit pilots to specify offsets in increments of 0.2 km (0.1 NM). SASP therefore undertook studies of the benefits of using small offsets ranging from 0.2 to 0.9 km (0.1 to 0.5 NM), and only to the right of centre line in order to reduce vertical risk in continental airspace. These offsets were typically called “micro-offsets”; and their (prospective) use was initially referred to as the “advanced strategic offset concept” (ASOC).

3.4.50 The November 2009 SASP meeting derived the formulas needed for the SASP to estimate the effects of ASOC on vertical risk, longitudinal risk, and lateral risk (ref. 32). ASOC (like SLOP) affects vertical risk and longitudinal risk by decreasing the lateral overlap probabilities experienced by aircraft assigned to the same route. Since vertical and longitudinal collision rates vary directly with lateral overlap probability, a decrease in lateral overlap probability causes proportional decreases in the rate of collisions due to the loss of planned vertical separation and the rate of collisions due to the loss of planned longitudinal separation.

3.4.51 It was estimated that the effects of ASOC on lateral risk for four different configurations of pairs of parallel routes:

a) each route is bi-directional, and uses the standard flight level allocation scheme: aircraft headed in an easterly direction fly on odd flight levels, while those headed in a westerly direction fly on even flight levels;

b) each route is unidirectional, and both routes carry traffic in the same direction;

c) each route is unidirectional, with its direction being opposite that of the other route. Each aeroplane has the opposite-direction traffic on its left; and

d) each route is unidirectional, with its direction being opposite that of the other route. Each aeroplane has the opposite-direction traffic on its right.

3.4.52 Aircraft equipped to apply micro-offsets were assumed also to be equipped with GNSS; and so the aircraft using the routes were grouped into three equipage classes: 1) those with neither GNSS, nor micro-offset capability; 2) those with GNSS, but not micro-offset capability; and 3) those with both GNSS and micro-offset capability. Aircraft capable of applying micro-offsets were required to do so; all others were required to aim for the centre line.

3.4.53 Also defined were six capability classes of *pairs* of aircraft, one for each of the six possible pairings of equipage levels. As in several other papers on the effects of lateral offsets, the probability of lateral overlap was taken to be a sum, each of whose terms is a product of two factors: 1) the probability that a randomly chosen pair is in a particular capability class, and has a particular intended separation; and 2) the (conditional) probability that the pair's aircraft are in lateral overlap, given that they are in that capability class and have that intended separation. Formulas were derived for the probability that a randomly chosen pair is in a particular capability class, and has a particular intended separation, for each of five flight-path configurations: 1) the aircraft are assigned to the same route, and are travelling in the same direction; 2) the aircraft are assigned to the same route, and are travelling in opposite directions; 3) the aircraft are assigned to different routes, and are travelling in the same direction; 4) the aircraft are assigned to different routes, and are travelling in opposite directions, with each aeroplane having the opposite-direction traffic on its left; and 5) the aircraft are assigned to different routes, and are travelling in opposite directions, with each aeroplane having the opposite-direction traffic on its right. The conditional probabilities of lateral overlap (given the capability class and intended separation of each randomly chosen pair of aircraft) were computed by two formulas based on convolutions of double-double-exponential (DDE) density functions: one formula for aircraft whose lateral deviations have the same DDE density function, and another formula for aircraft whose lateral deviations have different DDE density functions.

3.4.54 As parameter values characterizing the fleet in any particular airspace were not available, illustrative values were used in order to carry out computations that might be used to make reasonable conjectures as to the consequences of using micro-offsets (the parameters easily could have been set to other values, and the computations redone, had there been a need to do so). In all of the computations the fraction of flights with neither GNSS nor micro-offset capability was taken to be 0.3 ; the fraction of flights with GNSS, but not micro-offset capability, was taken to be 0.5; and the fraction of flights with both GNSS and micro-offset capability was taken to be 0.2. Of the 20 per cent of the fleet that was assumed to be capable of applying micro-offsets (and was required to do so) 15 per cent was assumed to use an offset of 0.2 km (0.1 NM), 20 per cent was assumed to use 0.4 km (0.2 NM), 25 per cent was assumed to use 0.6 km (0.3 NM), 30 per cent was assumed to use 0.7 km (0.4 NM), and 10 per cent was assumed to use 0.9 km (0.5 NM). The spacing between the routes in each pair was taken to be 14.8 km (8 NM). The lateral deviations of GNSS-equipped aircraft, from their intended paths, were assumed to be less than 0.28 km (0.15 NM) during 95 per cent of their flight time. The 95 per cent lateral containment distance for non-GNSS-equipped aircraft was assumed to be 2 NM. Both GNSS flights and non-GNSS flights were assumed to commit atypical navigation errors during 0.01 per cent of flight time. The wingspan of a "typical" aeroplane was conservatively assumed to be 0.05 km (0.03 NM).

3.4.55 For each of the four route configurations, percentage changes were computed in collision rates, due to the use of micro-offsets. In all four cases, the use of micro-offsets reduces the rate of collisions due to the loss of planned longitudinal separation, by 38.19 per cent. For aircraft travelling on unidirectional routes, the use of micro-offsets also reduces, by 38.19 per cent, the rate of collisions due to the loss of planned vertical separation. For aircraft travelling on bi-directional routes, the use of offsets reduces the rate of collisions due to the loss of an even number of flight levels of vertical separation, by 38.19 per cent; and it reduces the rate of collisions due to the loss of an odd number of flight levels of planned vertical separation, by 41.04 per cent. For aircraft travelling in the same direction on the same flight level of adjacent routes, the use of micro-offsets increases, by 0.75 per cent, the rate of collisions due to the loss of planned lateral separation. For aircraft travelling in opposite directions on the same flight level of adjacent parallel routes, and having opposite-direction traffic on the left, the use of offsets reduces the rate of collisions due to the loss of planned lateral separation, by 2.85 per cent. For aircraft travelling in opposite directions on the same flight level of adjacent parallel routes, and having opposite-direction traffic on the right, the use of offsets increases the rate of collisions due to the loss of planned lateral separation, by 4.36 per cent.

3.4.56 SASP concluded that the use of micro-offsets had significant potential to reduce rates of collision due to the loss of planned vertical separation, and that these potential reductions were likely, in most airspaces, to outweigh by far the slight increases in lateral risk that they might cause for certain route configurations.

SASP-WG/WHL/19 Meeting, May 2011

3.4.57 At its meeting of November 2010, SASP recognized that some air navigation service providers were considering the implementation of pairs of continental routes having spacings of 11.1 or 12.9 km (6 or 7 NM). These routes were to be restricted to aircraft that met the standard for RNP 1. Therefore, the panel asked for the ASOC computations to be redone with these two spacings and with the non-GNSS aircraft assumed to have 95 per cent containment of lateral errors within 1.9 km (1 NM) of the aircraft's intended path. Documentation at the May 2011 meeting provided those computations (ref. 38).

3.4.58 The method used in the documentation from the May 2011 was identical to the method used in the meeting of November 2009 (ref. 32). Using the revised parameter values in its calculations, the paper produced similar results.

3.4.59 As in the documentation from the SASP-WG/WHL/1, the SASP-WG/WHL/19 estimated percentage changes in risk for each of four route configurations. The use of micro-offsets reduces, by 36.28 per cent, the rate of collisions due to the loss of planned longitudinal separation. For aircraft traveling on unidirectional routes, the use of micro-offsets also reduces, by 36.28 per cent, the rate of collisions due to the loss of planned vertical separation. For aircraft traveling on bi-directional routes, the use of micro-offsets reduces by 36.28 per cent the rate of collisions due to the loss of an even number of flight levels of vertical separation, and reduces by 38.87 per cent the rate of collisions due to the loss of an odd number of flight levels of planned vertical separation. For aircraft traveling in the same direction on the same flight level of adjacent routes, the use of micro-offsets increases the rate of collisions due to the loss of planned lateral separation by negligibly small percentages: 0.04 per cent when the route spacing is 12.9 km (7 NM), and

0.07 per cent when the route spacing is 11.1 km (6 NM). For aircraft travelling in opposite directions on the same flight level of adjacent parallel routes, and having opposite-direction traffic on the left, the use of offsets reduces the rate of collisions due to the loss of planned lateral separation, by approximately 2 per cent: 1.66 per cent when the route spacing is 12.9 km (7 NM), and 1.95 per cent when the spacing is 11.1 km (6 NM). For aircraft traveling in opposite directions on the same flight level of adjacent parallel routes, and having opposite-direction traffic on the right, the use of offsets increases the rate of collisions due to the loss of planned lateral separation, by approximately 2 per cent: 1.77 per cent when the route spacing is 12.9 km (7 NM) and 2.13 per cent when the route spacing is 6 NM.

3.5 SAFETY ASSESSMENT FOR SLOP ON INTERSECTING TRACKS

3.5.1 This section summarizes the SASP safety assessment for the use of strategic lateral offsets on intersecting tracks. For the intersecting tracks case, emphasis has been on examining the increase, if any, in lateral collision risk due to the use of lateral offsets. Some consideration of the effect (reduction) on vertical and longitudinal collision risk was included in reference 15.

3.5.2 Analyses have been performed for two methods of applying lateral separation on intersecting tracks, namely the area of conflict method and the protected region of airspace method. The analyses described below in sections 3.5.4 to 3.5.35 are based on the former method whereas the analysis in section 3.5.36 is based on the latter.

3.5.3 Lateral collision risk on intersecting tracks varies with the track intersection angle, the nominal aircraft speeds and the offset scenario. In order to limit the number of angles and speed combinations to be evaluated for each offset scenario, the methodology used was first to determine the angle(s) and speed combination(s) for which the intersecting-tracks lateral collision risk without lateral offsets was the largest and next to evaluate the offset scenarios only for those angle(s) and speed combination(s).

SASP-WG/WHL/4 Meeting, November 2003 and SASP-WG/WHL/5 Meeting, May 2004

3.5.4 An initial analysis for RNAV 10 (RNP 10) navigational performance only based on the area of conflict method was presented in a paper at the SASP-WG/WHL/4 meeting (ref. 15). A paper at the SASP-WG/WHL/5 (ref. 18) considered three (typical) navigational performance cases. Both papers used intersecting-tracks lateral collision risk estimates without offsets from reference 53. The calculations assumed that both the along-track and across-track navigational error distributions were double exponential with the standard deviations derived from the 95 per cent containment values, i.e.

a) 7.4 km (4 NM) containment (95%): $\sigma_{across} = \sigma_{along}$ = 3.50 km (1.888 NM);

b) 18.5 km (10 NM) containment (95%): $\sigma_{across} = \sigma_{along}$ = 8.74 km (4.721 NM); and

c) 37 km (20 NM) containment (95%): $\sigma_{across} = \sigma_{along}$ = 17.49 km (9.442 NM).

3.5.5 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. See Figure 3-2. Lateral separation is achieved by the7 controller ensuring that two aircraft will not be simultaneously within the area of conflict at the same level (ref. 53). The methodology assumes distance reporting with a maximum reporting interval (*T*) dependent on the value of the separation minimum.

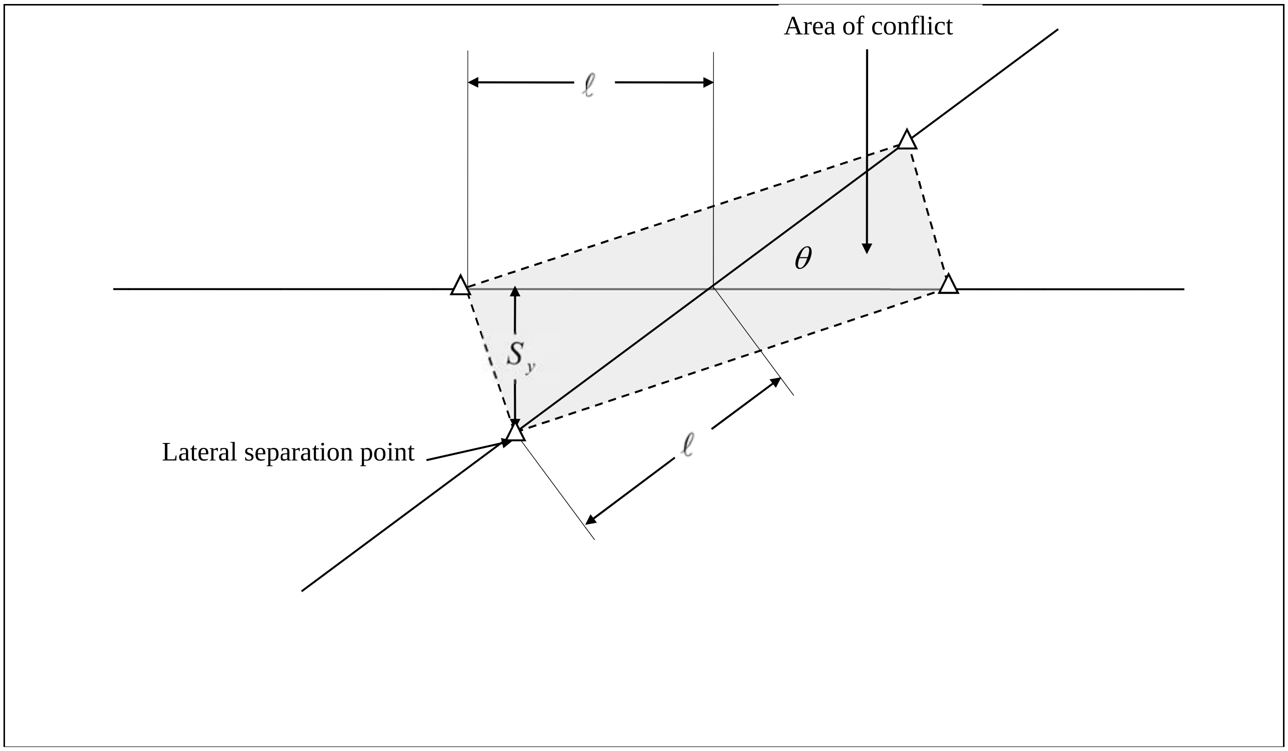

Figure 3-2: Lateral separation points and the area of conflict

3.5.6 The collision risk assessment utilized the following collision risk model:

$$CR(t_0,t_1) = 2.NP.\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1} HOP(t\,|\,V_1,V_2)\,P_z\big(h(t)\big)\left(\frac{2V_{rel}}{\pi\lambda_{xy}}+\frac{|\dot{z}|}{2\lambda_z}\right)g_1(V_1)g_2(V_2)dt.dV_1dV_2 \qquad (3.5.1)$$

The model calculates the collision risk $CR(t_0,t_1)$, expressed in fatal accidents per flight hour, over a suitable time interval $[t_0,t_1]$.

3.5.7 Most of the parameters in equation 3.5.1 above have their usual meaning, e.g. aircraft speeds and dimensions ($V_1, V_2, V_{rel}, |\dot{z}|, \lambda_{xy}, \lambda_z$), aircraft speed error probability densities ($g_1(V_1), g_2(V_2)$), the probability of vertical overlap ($P_z\big(h(t)\big)$), and the number of aircraft pairs passing an intersection per flight hour (NP). See reference 53.

3.5.8 The main parameter of the collision risk model in equation 3.5.1 is the conditional probability $HOP(t\,|\,V_1,V_2)$ of horizontal overlap at time 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 $HOP(t\,|\,V_1,V_2)$ depends critically on the along-track and across-track navigational error distributions, the intersection angle θ, and the distances of the two aircraft to the intersection at time t_0. These initial distances to the intersection can be expressed in terms of the reporting interval T and some other quantities. Lateral offsets enter into the nominal initial (and subsequent) locations of the two aircraft.

Lateral collision risk without SLOP

3.5.9 Two different cases were considered in reference 53, namely both aircraft approaching the area of conflict and one aircraft leaving the area of conflict as another one is entering (see Figure 3-3.) Risk computations were carried out for intersection angles between 15 and 165 degrees and all combinations of the following nominal speeds for the two aircraft: 300, 480, and 600 knots (kts).

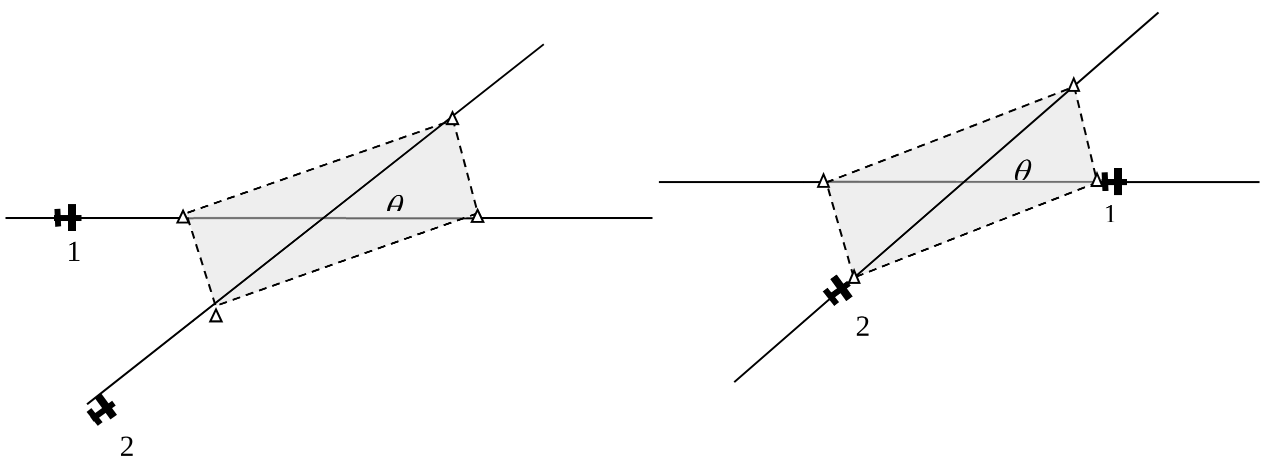

Figure 3-3. Aircraft approaching and leaving the area of conflict.

3.5.10 If both aircraft were approaching the area of conflict, the risk was largest at an intersection angle of 15 degrees. Risk estimates were approximately four orders of magnitude less than the TLS of 5×10^{-9} fatal aircraft accidents per flight hour for the combination of a 55.5 km (30 NM) lateral separation minimum 7.4 km (4 NM) containment (95per cent), and 14-minute reporting interval. Risk estimates were less than the TLS for the combination of a 93 km (50 NM) lateral separation minimum, 19 km (10 NM) containment (95per cent) and 27-minute reporting interval. (No risk computations were performed in reference 53 for the 37 km (20 NM) (95per cent) containment value, but this case was included in the SLOP risk assessment later (ref 18).)

3.5.11 If one aircraft was leaving the area of conflict as another one was entering, the risk was generally largest at 135 degrees. However, when aircraft deviations had 7.3 km (4 NM) containment the leaving aircraft had a nominal speed of 300 kts and the entering aircraft had a nominal speed of 600 kts, the maximum occurred at 97 degrees. Risk estimates were two to three orders of magnitude less than the TLS of 5×10^{-9} fatal aircraft accidents per flight hour for the combination of a 30 NM lateral separation minimum, 4 NM containment (95per cent), and 14 minute reporting interval. Risk estimates were also less than the TLS for the combination of a 50 NM lateral separation minimum, 19 km (10 NM) containment (95per cent), and 27-minute reporting interval. (No risk computations were performed for the 37 km (20 NM) (95per cent) containment value in reference 53.)

Lateral collision risk with SLOP

3.5.12 Thus, the lateral separation scenario without SLOP that showed the largest risk was the scenario in which two aircraft were on intersecting tracks differing by 135 degrees, with one aircraft just exiting the area of conflict while the other was just entering, with both aircraft at the same flight level. This situation is possible because of the hemispherical rule and is shown graphically in Figure 3-3. The figure also shows how lateral offsets to the right of track may increase or reduce the separation, dependent on whether the inbound (or outbound) aircraft has the other aircraft on the right or left.

3.5.13 References 15 and 18 presented intersecting-track lateral collision risk results for the above scenario with SLOP for offsets of 1.9 km (1 NM) or 3.7 km (2 NM) to the right of track. Reference 18 is an expanded version of reference 15. The collision risk model used for the SLOP calculations was the same as in equation (3.7.1), but with the offsets added to the aircraft's initial positions. The model was then run in the usual manner starting from the translated initial aircraft positions at time t_0 .

3.5.14 The results in tables 3-1 to 3-3 in the attachment below have been reproduced from reference 18. In the tables, a positive offset should be taken to mean "towards the other track", reducing the lateral separation between the aircraft (cf. figure 3-3, upper diagram) and a negative offset should be understood as "away from the other track", increasing the lateral separation (cf. Figure 3-3, lower diagram). In other words, a positive offset increases the lateral collision risk while a negative offset decreases the lateral collision risk.

3.5.15 The last column in each table shows "risk ratios", i.e. ratios between the lateral collision risks when offsets are used and when offsets are not used. Notice that the risk ratios are larger than one in the upper half of each table where the offsets are positive, i.e. are reducing the lateral separation and thus increasing the risk. Similarly, the risk ratios are smaller than one in the lower half of the table where the offsets are negative, i.e. are increasing the lateral separation and thus decreasing the risk. Not surprisingly, the largest risk ratios occur when both aircraft have the maximum offset of +3.7 km (2 NM).

3.5.16 The impact of SLOP on the intersecting-tracks lateral collision risk may now be assessed on the basis of the three tables in an absolute sense as well as in a relative sense. An absolute assessment involves comparing the risk estimates in the third column of the tables with the TLS. Notice that the risk unit used in the three tables is fatal accidents per billion flight hours. The converted value of the TLS is five fatal accidents per 1 000 million flight hours, i.e. all risk estimates should be less than five in the tables' risk unit. It follows from the tables that for the 55.5 km (30 NM) separation minimum and 4 NM containment (95 per cent) as well as for the 185 km (100 NM) separation minimum and 37 km (20 NM) containment (95 per cent), all risk estimates are below the converted upper limit of five (fatal accidents per billion flight hours). There are six individual cases in table 3-2 for the 93 km (50 NM) separation minimum and 19 km (10 NM) containment (95 per cent) where the upper limit of 5 (fatal accidents per billion flight hours) is exceeded, namely for the offset combinations ranging from (+1, +1) to (+2, +2). However, the lateral collision risk without offsets is also relatively high in table 3-2. In a relative sense, the highest risk ratios occur for the 30 NM separation minimum and 7.3 km (4 NM) containment (95 per cent).

3.5.17 In practice, all the different offset combinations would be expected to be used, and averaging the individual risk estimates over the various offset combinations is appropriate. The computed averages are shown in the last row of each table and are seen to be less than the upper limit of five fatal accidents per billion flight hours.

3.5.18 In addition to the lateral risk ratios reproduced in Tables 3-1 to 3-3, of documentation from the SASP-WG/WHL/5 meeting (ref. 18) included some longitudinal and vertical risk ratios as well as combined risk ratios. The largest combined risk ratio was found to be 1.040 for the 93 km (50 NM) separation minimum and 19 km (10 NM) containment (95 per cent), i.e. an increase in the overall collision risk by only a few percentage points.

SASP-WG/WHL/18 Meeting, November 2010

3.5.19 The subject of the impact of lateral offsets on intersecting-tracks lateral collision risk was discussed at the SASP-WG/WHL/17 meeting in May 2010. During the discussion, reference was made to the analyses summarized in section 3.5.1 above and the mathematicians' subgroup was requested to perform a similar analysis for RNAV 2 navigation performance and micro offsets in one tenth of a nautical mile up to a maximum of 0.9 km (0.5 NM). See operational requirement 22 in reference 58.

3.5.20 Documentation for the SASP-WG/WHL/18 meeting provided the requested analysis (ref. 35). The same approach was followed as in references 15 and 18 to limit the number of cases to be evaluated, i.e. it was first determined which combinations of intersection angle and aircraft speed gave the largest collision risk without the use of lateral offsets. Lateral collision risk when SLOP is used was then computed only for the pertinent combination(s). The same collision risk model of equation 3.5.1 was also used but with the navigational error distributions and parameter values adapted to the RNAV 2 navigation specification and separation minimum.

3.5.21 The collision risk calculations considered typical navigational errors only. The calculations assumed that for the given PBN navigation specification the along-track and across-track navigational error distributions were the same. In conformity with a decision of the mathematicians' subgroup, reached at the SASP-WG/WHL/18 meeting (ref. 54), RNAV navigational errors were modelled with a double exponential probability distribution and the standard deviation was determined from the 95 per cent containment requirement as $\sigma_{across} = \sigma_{along} = 0.944$ NM.

Lateral collision risk without SLOP

3.5.22 The first step was to compute intersecting-track lateral collision risk without the use of lateral offsets for intersection angles between 5 degrees and 175 degrees inclusive. Nine different combinations of nominal aircraft speed were evaluated for each intersection angle, as the speed of each aeroplane in a pair was taken to be 300, 480, or 600 kts. An intersecting-track lateral separation minimum of 27.8 km (15 NM) was used for the analysis involving RNAV 2 aircraft, as was the case in reference 58. Following reference 18, computations were performed only for the case in which one aircraft is leaving the area of conflict as another one is entering it, since this case had given larger risks than the case in which both aircraft were approaching the area of conflict.

3.5.23 It should be noted that when the area-of-conflict method is utilized (paragraph 3.5.2.2 and figure 3-2) the intersecting-track lateral risk depends on the reporting times of the aircraft. The (initial) computations assumed a reporting interval *T* of 14 minutes, i.e. the same value as used for the 4 NM 95 per cent navigational accuracy case in reference 18.

3.5.24 The greatest collision risk was found for each combination of nominal aircraft speeds at an intersection angle of 95 degrees. Unfortunately, it was also found that the estimated lateral collision risk exceeded the TLS of 5×10^{-9} fatal accidents per flight hour for many intersection angles when the nominal speed of the outbound aircraft was 300 kts. The lateral risk then increased with the nominal speed of the inbound aircraft.

3.5.25 Therefore, the computations without lateral offsets were repeated using a reporting interval of T = 10 minutes rather than the previously used 14 minutes. The newly computed risk estimates showed that the TLS of 5×10^{-9} fatal accidents per flight hour was then well met for all intersection angles and nominal speed combinations of the two aircraft. The greatest risk continued to be found at a 95 degrees intersection angle.

Lateral collision risk with SLOP

3.5.26 The effect of using lateral offsets in increments of one tenth of a nautical mile, up to a maximum of 0.9 km (0.5 NM) to the right of track was then evaluated for a 95 degree intersection angle only. The computations were restricted to lateral offsets of 0.2, 0.6 and 0.9 km (0.1, 0.3 and 0.5 NM). Table 3-4 shows the results of the computations for the least favourable combination of aircraft speeds, i.e. 300 kts for the outbound aircraft and 600 kts for the inbound aircraft. In the same manner as in section 3.5.2, a positive offset should be taken to mean “towards the other track” whereas a negative offset means “away from the other track”. Recall Figure 3-3 above. Thus, a positive offset reduces the lateral separation of the tracks while a negative offset increases the lateral separation. Consequently, a positive offset increases the lateral collision risk while a negative offset decreases the lateral collision risk.

3.5.27 It follows from table 3-4 that all the risk estimates but one are less than the TLS of 5×10^{-9} fatal aircraft accidents per flight hour. Not surprisingly, the exception concerns the case in which both aircraft have the maximum offset of + 0.9 km (0.5 NM) towards each other. In fact, the TLS is exceeded marginally by a little less than 4 per cent. The average lateral collision risk over all 32 offset scenarios from table 3-4 amounts to 2.90×10^{-9} fatal accidents per flight hour and meets the TLS. The average risk when lateral offsets are used is approximately 6 per cent larger than the lateral collision risk without the use of lateral offsets.

3.5.28 The last column in table 3-4 shows risk ratios, i.e. ratios between the lateral collision risks when offsets are used and when offsets are not used. Notice that the risk ratios are larger than one in the upper half of the table where the offsets are positive, i.e. are reducing the lateral separation and thus increasing the risk. Similarly, the risk ratios are smaller than one in the lower half of the table where the offsets are negative, i.e. are increasing the lateral separation and thus decreasing the risk.

3.5.29 The SASP-WG/WHL/18 meeting (ref. 35) also presented results for the more favourable aircraft speed combinations of 480 and 600 kt, for each of the inbound and outbound aircraft, and for the original reporting interval of 14 minutes (rather than the reduced interval of 10 minutes). Although the relative effect, as measured by the risk ratios was larger for these two cases, in an absolute sense, all collision risk estimates were well below the TLS.

3.5.30 Having shown that risk estimates for aircraft assigned to intersecting tracks are less than the TLS when the aircraft meet RNAV 2 and use micro-offsets, the separation minimum is 27.8 km (15 NM), and the separation is applied through the "area of conflict" method, concluded that the use of micro-offsets under those conditions would be acceptably safe.

SASP-WG/WHL/19 Meeting, May 2011

3.5.31 Following the presentation at the SASP-WG/WHL/18 meeting (ref. 35), SASP required further work on the effect of micro-offsets on intersecting-track lateral collision risk for RNAV 2 aircraft and a 15 km (8 NM) lateral separation minimum, as well as for RNP 1 aircraft and 11.1 and 13 km and (6 and 7 NM) lateral separation minima.

3.5.32 Documentation at the SASP-WG/WHL/19 meeting addressed this further work (ref. 39). The objective was to use the same methodology as in references 15, 18, and 35, i.e. to first determine the angle(s) and speed combination(s) for which the intersecting-tracks lateral collision risk without lateral offsets is the largest and to next evaluate the offset scenarios only for those angle(s) and speed combinations(s).

3.5.33 However, it was found that, for many intersection angles, the lateral risk when offsets were not used did not meet the TLS. In this context, it is worth noting that, according to reference 39, computations had not yet been carried out for intersecting-track lateral risk when the aircraft met RNAV 2 or RNP 1, the separation minima were 14.8 km (8 NM) (for RNAV 2) and 6 (or 7) NM (for RNP 1), and the area-of-conflict method was used to apply lateral separation. Recall also that the RNAV 2 calculations in reference 35 were based on a much larger lateral separation minimum of 27.8 km (15 NM).

3.5.34 As was noted in 3.5.2 and 3.5.3, one of the factors that influences the intersecting-track lateral collision risk under the area of conflict scenario is the length of the reporting interval *T*. Within certain limits, it is possible to reduce the risk estimates by more frequent position reporting, i.e. by reducing the reporting interval. Rather than making unjustified choices concerning operationally useful reporting intervals, the author of reference 39 chose to seek advice from operational experts at the SASP-WG/WHL/19 meeting before performing the intended lateral offset calculations, and simply to present the results of the calculations which assumed that lateral offsets were not used.

3.5.35 Following the presentation of reference 39 at the SASP-WG/WHL/19 meeting, the SASP concluded that the analysis should not be pursued because the "area of conflict" method had been withdrawn from the PANS-ATM in favour of a method that requires a "protected region" of airspace on each side of the track of a reference aircraft (cf. paragraph 3.3.4). The mathematicians' subgroup was asked to consider whether SLOP analysis for the latter method would be required and, if necessary, to perform the pertinent analysis.

SASP-WG/1 Meeting, November 2011

3.5.36 Documentation at the SASP-WG/1 meeting assumed the use of the protected region of airspace method (ref. 48), and provided an assessment of the impact of both conventional offsets and micro-offsets (1, 2, and 0.1 NM – 0.5 NM, respectively). The paper covered the following cases, previously analysed for the area of conflict method in references 15, 18, 35, and 39:

a) RNAV 2, 27.8 km (15 NM) lateral separation minimum and micro-offsets;

b) RNAV 2, 14.8 km (8 NM) lateral separation minimum and micro-offsets;

c) RNP 1, 13 km (7 NM) lateral separation minimum and micro-offsets;

d) RNP 1, 11.1 km (6 NM) lateral separation minimum and micro-offsets;

e) RNP 4, 55.5 km (30 NM) lateral separation minimum and conventional offsets;

f) RNP 4, 27.8 km (15 NM) lateral separation minimum and conventional offsets; and

g) RNAV 10 (RNP 10), 93 km (50 NM) lateral separation minimum and conventional offsets.

3.5.37 The method of applying lateral separation to aircraft assigned to intersecting tracks, by using a protected region of airspace *S* on either side of the track of a reference aircraft (aircraft 1) was presented at the SASP-WG/WHL/13 (ref. 55). A second aircraft flying on an intersecting track, which does not have longitudinal or vertical separation from the reference aircraft, would be required to change flight level before entering the protected region, and not to return to the original level until clear of the protected region (see Figure 3-4). Unlike the area of conflict method, the method based on a protected region of airspace does not assume periodic distance reporting.

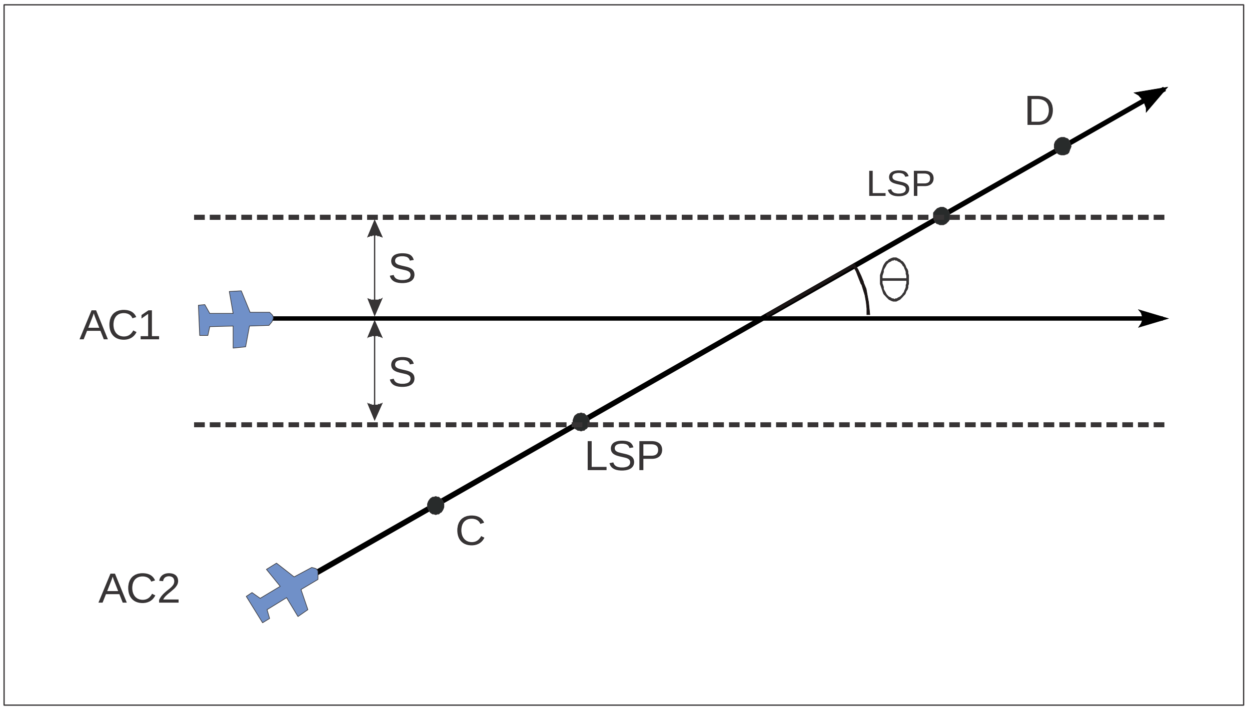

Figure 3-4. Two aircraft are at the same flight level on intersecting tracks. To ensure separation aircraft 2 will be required to climb/descend at C and reach another level by its first lateral separation point (LSP). Similarly, once it has passed the track of aircraft 1, aircraft 2 can descend/climb only after reaching its second LSP. Position D shows where aircraft 2 would regain its original flight level.

3.5.38 The collision risk assessment for all the cases listed in paragraph 3.5.4.1 utilized the following collision risk model:

$$CR(t_0,t_1) = 2.NP.\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1} HOP(t\,|\,V_1,V_2)\,P_z\big(h(t)\big)\left(\frac{2V_{rel}}{\pi\lambda_{xy}}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right)g_1(V_1)\,g_2(V_2)\,dt.dV_1dV_2 \quad (3.5.2)$$

The model calculates the collision risk $CR(t_0,t_1)$, expressed in fatal accidents per flight hour, over a time interval $CR(t_0,t_1)$ 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.

3.5.39 Although the form of the model in equation 3.5.2 looks the same as that of the model in equation 3.5.1 in section 3.5.2, the actual calculations are quite different, particularly with regard to the time interval $[t_0,t_1]$ and the probability of vertical overlap over time, $P_z(h(t))$. Another major difference is that the form of the model in eq. (3.5.2) no longer depends on a periodic reporting interval *T*. See reference 55 for further details.

3.5.40 Most of the parameters in equation 3.5.2 above have their usual meaning, such as aircraft speeds and dimensions ($V_1, V_2, V_{rel}, \overline{|\dot{z}|}, \lambda_{xy}, \lambda_z$), aircraft speed error probability density functions ($g_1(V_1)$, $g_2(V_2)$), the probability of vertical overlap $P_z(h(t))$, and the number of aircraft pairs passing an intersection per flight hour (*NP*). See references 53 and 55.

3.5.41 The main parameter of the collision risk model in equation 3.5.2 is $HOP(t\,|\,V_1,V_2)$, the conditional probability of horizontal overlap at time *t* given the aircraft speeds V_1 and V_2. Apart from its dependence on *t*, V_1 and V_2, this 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.

3.5.42 The collision risk calculations performed for the "protected region" method (ref. 55) departed from those for the "area of conflict" method (ref. 53) in that the risk was calculated with different starting positions for the reference aircraft at time t_0, including positions on 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 aircraft ground speeds of 300, 480 and 600 kts.

3.5.43 To limit the number of scenarios that would have to be evaluated, intersecting-track lateral risk was calculated first for intersection angles between 5 degrees and 175 degrees, under the assumption that offsets were not used. The lateral offset calculations were then carried out only for the intersection angle which gave the largest risk for each of the seven combinations of navigation specification, separation minimum and conventional offset or micro-offset.

3.5.44 All collision risk calculations considered typical navigational errors only. The calculations assumed that for each PBN navigation specification the along-track and across-track navigational error distributions were the same. In conformity with the mathematicians' subgroup decision at the SASP meeting of November 2006 (ref. 54), RNAV navigational errors were modelled with a double exponential probability distribution with the standard deviation determined from the 95 per cent containment requirement and RNP navigational errors were modelled with a Gaussian probability distribution with the standard deviation determined from the 99.999 per cent containment requirement.

RNAV 2

3.5.45 For RNAV 2 aircraft whose assigned lateral separation is at least 27.8 km (15 NM), the largest intersecting-track risk, without the use of offsets (maximized over all starting positions of aircraft 1, and over all speed combinations of the two aircraft from 300, 480 and 600 kts), was found to be at a five-degree intersection angle. Thus, lateral offset calculations were performed for this intersection angle only and micro-offsets of 0.2, 0.6 and 0.9 km (0.1, 0.3 and 0.5 NM). Table 3-5 shows the resulting collision risk estimates together with “risk ratios” in the table’s last column. As before, each risk ratio is the ratio of lateral risk when offsets are used to lateral risk when offsets are not used. The effect of the offsets on collision risk seems to vary with the magnitude of the offset of aircraft 1, which seems to be consistent with the methodology from reference 55, since this methodology maximizes the risk over the starting position of aircraft 1. Compared with the no-offsets case, the maximum increase in the risk is by a factor of approximately 2. Nonetheless, all the risk estimates for the offsets case remain at least an order of magnitude below the TLS of 5×10^{-9} fatal accidents per flight hour. The average risk ratio is 1.44 and the average risk over the various offset scenarios is 2.24×10^{-10} fatal accidents per flight hour.

3.5.46 For RNAV 2 aircraft whose lateral separation is at least 14.8 km (8 NM), the lateral risk when offsets are not used (maximized over all starting positions of aircraft 1, and over all speed combinations of the two aircraft) was found to meet the TLS of 5×10^{-9} fatal accidents per flight hour only for intersection angles between 30 degrees and 150 degrees inclusive.

3.5.47 Lateral offset calculations were then performed for three micro-offset distances (0.1 , 0.3 , and 0.5 NM), and for nine intersection angles, including small (5 and 15 degrees) and large (165 and 175 degrees) angles at which the TLS was not met when calculations assumed that offsets were not used. The resulting risk ratios are shown in table 3-6. They are very similar to those in table 3-5, for a 27.8 km (15 NM) lateral separation minimum. The effect of the offsets on collision risk again seems to vary with the magnitude of the offset of aircraft 1. The use of offsets increases risk by, at most, a factor of approximately 2; and the average risk ratios for the intersection angles vary between 1.41 and 1.46.

3.5.48 Applying the risk ratios of table 3-6 to the risk estimates for a system in which offsets are not used, the SASP found that the TLS would be met for intersection angles between 35 degrees and 145 degrees inclusive (thus the range of angles at which the TLS could be met, decreased from that of the no-offsets case by 5 degrees on each end).

RNP 1

3.5.49 For RNP 1 approved aircraft whose assigned lateral separation was at least 13 km (7 NM), the (maximized) intersecting-track lateral risk without the use of offsets was found to be negligible for all intersection angles between 5 and 175 degrees inclusive, i.e. of the order of 10^{-34} to 10^{-32} fatal accidents per flight hour. It is remarked that intersecting-track lateral risk for this navigation specification and separation minimum had not previously been calculated.

3.5.50 Despite the extremely small risk values for the no-offsets case with RNP 1 and a 13 km (7 NM) lateral separation minimum, lateral offset calculations were performed (as a matter of interest) in the same manner as described for the RNAV 2 case above for micro-offsets of 0.1, 0.3 and 0.5 NM. As measured in a relative sense by the risk ratios, offsets of 0.6 and 0.9 km (0.3 and 0.5 NM) for aircraft 1 were found to have a substantial effect. However, measured in an absolute sense against the TLS of 5×10^{-9} fatal accidents per flight hour, they had a negligible impact on the safety of the pertinent operation, with values of the order of 10^{-30} to 10^{-28} fatal accidents per flight hour.

3.5.51 For RNP 1 approved aircraft operating with a 11.1 km (6 NM) lateral separation minimum, the (maximized) intersecting-track collision risk without the use of offsets was also found to be negligible for all intersection angles between 5 degrees and 175 degrees inclusive, viz. of the order of 10^{-26} to 10^{-25} fatal accidents per flight hour. Intersecting-track lateral collision risk for this combination of navigation specification and separation minimum also had not previously been calculated.

3.5.52 In the same manner as for RNP 1 and a 13 km (7 NM) lateral separation minimum, lateral offset calculations were performed as a matter of interest for the 11.1 km (6 NM) lateral separation minimum, for micro offsets of 0.1, 0.3 and 0.5 NM. The risk ratios for offsets of 0.6 and 0.9 km (0.3 and 0.5 NM) were still large, but smaller than for RNP 1 and the 13 km (7 NM) lateral separation minimum. Again, measured in an absolute sense against the TLS of 5×10^{-9} fatal accidents per flight hour, they had a negligible impact on the safety of the pertinent operation, with values of the order of 10^{-22} fatal accidents per flight hour.

RNP 4

3.5.53 For RNP 4 approved aircraft, and operating with a 55.5 km (30 NM) lateral separation minimum, the (maximized) intersecting-track collision risk without the use of offsets was also found to be negligible for all intersection angles between 5 degrees and 175 degrees inclusive, i.e. of the order of 10^{-37} to 10^{-34} fatal accidents per flight hour.

3.5.54 As was done for the other combinations of navigation specification and separation minimum for which the collision risk was found to be negligible in the no-offsets case, lateral-offset calculations were performed as a matter of interest. However, for RNP 4 aircraft, conventional offsets of 1.9 and 3.7 km (1 and 2 NM) were used. The effect of the offsets on collision risk again varied with the magnitude of the offset of aircraft 1. Fairly large risk ratios were found for the maximum lateral offset of 3.7 km (2 NM) for aircraft 1. However, in an absolute sense, the intersecting-track lateral collision risk, for aircraft using offsets of 1.9 or 3.7 km (1 or 2 NM), remained negligible, viz. of the order of 10^{-33} to 10^{-30} fatal accidents per flight hour, depending on the intersection angle.

3.5.55 The SASP next considered the risk for aircraft that meet the RNP 4 navigation specification and operate with a 27.8 km (15 NM) lateral separation minimum, but without using lateral offsets. It was found that the reduction of the lateral separation minimum, from 55.5 to 27.8 km (30 to 15 NM), gave rise to a significant increase in collision risk estimates. (As before, the risk was maximized over all starting positions of aircraft 1, and over all speed combinations of the two aircraft, from 300, 480, and 600 kts.) The risk values for most intersection angles were still several orders of magnitude smaller than the TLS of 5×10^{-9} fatal accidents per flight hour. The largest values occurred for the 5 degree and 175 degree intersection angles and were also well below the TLS.

3.5.56 Lateral offset calculations were then performed for nine intersection angles, including small (5- and 15-degree) and large (165- and 175-degree) angles, and offsets of 1.9 and 3.7 km (1 and 2 NM). The resulting risk ratios are shown in Table 3-7 and are seen to vary mainly with the offset of aircraft 1. They are of the order of magnitude of 10 when aircraft 1 has a 1 NM offset and of the order of 100 when aircraft 1 has a 3.7 km (2 NM) offset. In the latter case, the TLS of 5×10^{-9} fatal accidents per flight hour was exceeded by a factor of approximately three for the smallest intersection angle of 5 degrees. Averaged over the eight offset cases and the no-offset case, the collision risk for the 5 degree intersection angle equalled 5.16×10^{-9} fatal accidents per flight hour, which is just over the TLS. However, it should be kept in mind that all collision risk estimates for the protected region of airspace method considered in this subsection (3.5.5) are maximum collision risk values. Thus, the increase in the risk due to 3.7 km (2 NM) offsets may be considered to be just tolerable for the 5 degree intersection angle. There was no problem meeting the TLS in the offset case for the next-smallest angles of 10 and 15 degrees (ref. 48). The only additional critical case was the 175 degree intersection angle for which the result was somewhat worse than for the 5 degree angle, viz. an average collision risk of 6.36×10^{-9} fatal accidents per flight hour. The two values exceeding the TLS were deemed to be tolerable since averaging over the starting position of aircraft 1 brings both values below the TLS. For all remaining intersection angles, the collision risk estimates when using offsets of 1.9 or 3.7 km (1 or 2 NM) were well below the TLS.

RNAV 10 (RNP 10)

3.5.57 Consider finally the lateral collision risk for aircraft that meet the RNAV 10 (RNP 10) navigation specification and fly in airspace where a 93 km (50 NM) lateral separation minimum is applied. For this case, collision risk without the use of lateral offsets was calculated for intersection angles between 5 and 175 degrees inclusive, using the “protected airspace” methodology, i.e. maximized over all starting positions of aircraft 1, and over all speed combinations of the two aircraft from 300, 480, and 600 knots (kts.). The results were cross-checked against those of previous calculations reported in references 56 and 57.

3.5.58 As was noted in reference 56, the calculated risk values were less than the TLS of 5×10^{-9} fatal accidents per flight hour only for intersection angles between 40 degrees and 135 degrees inclusive. It was also noted in reference 56 that maximizing the collision risk over all starting positions of aircraft 1 was over-conservative. Testing the maximum risk against the TLS is an efficient way to prove the safety of a procedure, when it works. It is, however, a stricter test than necessary. Consequently, two methods for averaging the risk over the starting position of aircraft 1 were examined in reference 57.

3.5.59 Ref. 48 did not utilize either of these two averaging methods but proceeded with the original “protected airspace” method of estimating risk for aircraft assigned to intersecting tracks. It then applied a correction factor for the reduction in collision risk due to averaging as opposed to maximization. Averaging over the starting positions of aircraft 1 was found to reduce the maximum risk by a factor that varied between approximately 2.1 and 3.6, and depended on the intersection angle (Refs. 48 and 57).

3.5.60 Lateral offset calculations were then performed for 10 intersection angles, including small (5- and 15-degree) and large (165- and 175-degree) angles, and offsets of 1.9 and 3.7 km (1 and 2 NM). The resulting risk ratios are shown in Table 3-8 and are again seen to vary mainly with the offset of aircraft 1. The pattern in the risk ratios is fairly uniform over the intersection angle, with the average values by intersection angle ranging from 1.36 to 1.39.

3.5.61 Application of both the risk ratios and the correction factors for average/maximum risk (see ref. 48) yielded the risk values shown in Table 3-9. For comparison, the corresponding risk estimates without the use of lateral offsets are also shown in the table. With one exception – an intersection angle of 145 degrees – the use of lateral offsets does not change the key conclusion as to whether or not the TLS is met.

3.6 HAZARD ASSESSMENT

3.6.1 As was stated in Section 3.3.5, 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 sub-sections 3.4 and 3.5, the following paragraphs deal briefly with the safety assessment for the other hazards.

3.6.2 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 the development of ATM procedures. 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.

3.7 CONCLUSIONS

3.7.1 The application of the SASP process demonstrated that the application of the SLOP as detailed in this document has been determined as being safe. SASP also identified a number of hazards together with appropriate mitigations and controls.

3.7.2 Notwithstanding the above, there is a requirement for a region or State to undertake an implementation safety assessment outlined in Doc 4444 Chapter 2, ATS Safety Management. 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.

3.7.3 To assist regions and States with their implementation safety assessment, a State implementation plan is provided in chapter 4. This plan will be seen to rely upon the various outputs from the application of the SASP safety assessment.

Attachment to Chapter 3

Table 3-1. Results for lateral separation on intersecting tracks with right offsets; 30 NM lateral separation minimum, 4 NM containment (95 per cent), and 14-minute reporting interval. The risk figures are in units of fatal accidents per 1000 million flight hours.

Offset (a/c 1) NM	*Offset (a/c 2) NM*	*Lateral Risk Estimate*	*Lateral Risk Ratio*
0	0	0.0305	1.000
0	+1	0.0577	1.891
+1	0	0.0416	1.362
+1	+1	0.0781	2.559
0	+2	0.1072	3.510
+2	0	0.0566	1.855
+2	+1	0.1057	3.462
+1	+2	0.1440	4.716
+2	+2	0.1933	6.329
0	0	0.0305	1.000
0	-1	0.0159	0.521
-1	0	0.0224	0.733
-1	-1	0.0116	0.380
0	-2	0.0082	0.269
-2	0	0.0164	0.539
-2	-1	0.0085	0.278
-1	-2	0.0060	0.195
-2	-2	0.0044	0.142
Average		0.0521	1.678

Table 3-2. Results for lateral separation on intersecting tracks with right offsets; 50 NM lateral separation minimum, 10 NM containment (95 per cent), and 27-minute reporting interval. The risk figures are in units of fatal accidents per billion flight hours.

Offset (a/c 1) NM	*Offset (a/c 2) NM*	*Lateral Risk Estimate*	*Lateral Risk Ratio*
0	0	3.38	1.000
0	+1	4.53	1.340
+1	0	4.38	1.295
+1	+1	5.86	1.735
0	+2	6.06	1.794
+2	0	5.67	1.677
+2	+1	7.59	2.246
+1	+2	7.84	2.322
+2	+2	10.15	3.005
0	0	3.38	1.000
0	-1	2.52	0.746
-1	0	2.61	0.772
-1	-1	1.95	0.576
0	-2	1.88	0.557
-2	0	2.01	0.596
-2	-1	1.50	0.444
-1	-2	1.45	0.429
-2	-2	1.12	0.331
Average		4.10	1.215

Table 3-3. Results for lateral separation on intersecting tracks with right offsets; 100 NM lateral separation minimum, 20 NM containment (95 per cent), and 27-minute reporting interval. The risk figures are in units of fatal accidents per billion flight hours.

Offset (a/c 1) NM	*Offset (a/c 2) NM*	*Lateral Risk Estimate*	*Lateral Risk Ratio*
0	0	1.02	1.000
0	+1	1.16	1.140
+1	0	1.18	1.158
+1	+1	1.35	1.320
0	+2	1.33	1.300
+2	0	1.37	1.341
+2	+1	1.56	1.529
+1	+2	1.54	1.505
+2	+2	1.78	1.743
0	0	1.02	1.000
0	-1	0.89	0.877
-1	0	0.88	0.863
-1	-1	0.77	0.757
0	-2	0.78	0.769
-2	0	0.76	0.746
-2	-1	0.67	0.654
-1	-2	0.68	0.664
-2	-2	0.59	0.573
Average		1.07	1.052

Table 3-4. Results for lateral separation on intersecting tracks with micro-offsets to the right; 15 NM lateral separation minimum, RNAV 2 aircraft, nominal speed of outbound aircraft 300 kt, nominal speed of inbound aircraft 600 kt, and a 10-minute reporting interval. The risk figures are in units of fatal accidents per flight hour.

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Lateral collision risk*	*Risk ratio*
0.0	0.0	2.73E-09	1.00
0.0	+ 0.1	2.94E-09	1.08
0.0	+ 0.3	3.42E-09	1.25
0.0	+ 0.5	3.98E-09	1.46
+ 0.1	0.0	2.87E-09	1.05
+ 0.1	+ 0.1	3.09E-09	1.13
+ 0.1	+ 0.3	3.60E-09	1.32
+ 0.1	+ 0.5	4.19E-09	1.54
+ 0.3	0.0	3.18E-09	1.17
+ 0.3	+ 0.1	3.43E-09	1.26
+ 0.3	+ 0.3	3.99E-09	1.46
+ 0.3	+ 0.5	4.65E-09	1.71
+ 0.5	0.0	3.54E-09	1.30
+ 0.5	+ 0.1	3.82E-09	1.40
+ 0.5	+ 0.3	4.44E-09	1.63
+ 0.5	+ 0.5	5.18E-09	1.90
0.0	0.0	2.73E-09	1.00
0.0	- 0.1	2.53E-09	0.93
0.0	- 0.3	2.18E-09	0.80
0.0	- 0.5	1.88E-09	0.69
- 0.1	0.0	2.60E-09	0.95
- 0.1	- 0.1	2.41E-09	0.88
- 0.1	- 0.3	2.08E-09	0.76

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Lateral collision risk*	*Risk ratio*
- 0.1	- 0.5	1.79E-09	0.66
- 0.3	0.0	2.36E-09	0.87
- 0.3	- 0.1	2.19E-09	0.80
- 0.3	- 0.3	1.89E-09	0.69
- 0.3	- 0.5	1.64E-09	0.60
- 0.5	0.0	2.16E-09	0.79
- 0.5	- 0.1	2.01E-09	0.74
- 0.5	- 0.3	1.74E-09	0.64
- 0.5	- 0.5	1.50E-09	0.55

Table 3-5. Results for lateral separation on intersecting tracks with micro offsets to the right; 15 NM lateral separation minimum, RNAV 2 aircraft, 5-degree intersection angle. The risk figures are in units of fatal accidents per flight hour.

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Lateral collision risk*	*Risk ratio*
0	0	1.56E-10	1.00
0	0.1	1.56E-10	1.00
0	0.3	1.56E-10	1.00
0	0.5	1.56E-10	1.00
0.1	0	1.80E-10	1.15
0.1	0.1	1.81E-10	1.16
0.1	0.3	1.80E-10	1.15
0.1	0.5	1.80E-10	1.15
0.3	0	2.40E-10	1.54
0.3	0.1	2.41E-10	1.54
0.3	0.3	2.40E-10	1.54
0.3	0.5	2.40E-10	1.54
0.5	0	3.21E-10	2.06
0.5	0.1	3.22E-10	2.06
0.5	0.3	3.20E-10	2.05
0.5	0.5	3.20E-10	2.05
Average		2.24E-10	1.44

Table 3-6. Risk ratios for RNAV 2 aircraft with right offsets and an 8 NM lateral separation minimum for various intersection angles.

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Risk ratio*								
		θ = 5º	*θ = 15º*	*θ = 30º*	*θ = 45º*	*θ = 90º*	*θ = 135º*	*θ = 150º*	*θ = 165º*	*θ = 175º*
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	0.1	0.99	1.00	1.00	1.00	1.00	1.01	1.01	1.00	1.00
0	0.3	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.99
0	0.5	1.00	1.00	1.01	0.99	1.00	1.00	1.00	1.00	1.00
0.1	0	1.15	1.15	1.16	1.16	1.15	1.16	1.16	1.16	1.15
0.1	0.1	1.14	1.15	1.16	1.16	1.15	1.17	1.17	1.16	1.15
0.1	0.3	1.15	1.16	1.16	1.16	1.15	1.16	1.16	1.15	1.14
0.1	0.5	1.15	1.15	1.17	1.15	1.15	1.16	1.16	1.16	1.15
0.3	0	1.52	1.54	1.57	1.56	1.52	1.57	1.56	1.54	1.52
0.3	0.1	1.51	1.55	1.57	1.56	1.52	1.58	1.58	1.55	1.52
0.3	0.3	1.52	1.55	1.57	1.57	1.52	1.57	1.57	1.54	1.51
0.3	0.5	1.51	1.54	1.58	1.56	1.52	1.57	1.57	1.55	1.52
0.5	0	2.01	2.06	2.11	2.11	2.00	2.11	2.10	2.05	2.01
0.5	0.1	2.00	2.06	2.12	2.11	2.00	2.13	2.12	2.06	2.01
0.5	0.3	2.01	2.07	2.12	2.11	2.00	2.12	2.12	2.05	1.99
0.5	0.5	2.00	2.06	2.13	2.11	2.00	2.12	2.10	2.06	2.01
Average		1.42	1.44	1.46	1.46	1.42	1.46	1.46	1.44	1.41

Table 3-7. Risk ratios for RNP 4 aircraft with right offsets and a 15 NM lateral separation minimum for various intersection angles.

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Risk ratio*								
				θ = 30º	*θ = 45º*	*θ = 90º*	*θ = 135º*	*θ = 150º*	*θ = 165º*	*θ = 175º*
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	1	1.00	1.00	0.90	1.03	1.00	0.97	1.20	1.00	1.00
0	2	1.00	1.01	1.05	1.05	1.00	0.95	1.13	1.00	1.01
1	0	11.15	14.30	10.18	10.16	8.84	10.07	10.00	14.15	10.99
1	1	11.15	14.30	9.21	10.41	8.84	9.86	9.79	14.15	10.99
1	2	11.15	14.39	10.71	10.66	8.84	9.59	11.28	14.15	11.05
2	0	106.11	174.56	88.98	88.71	78.01	86.99	86.10	171.71	103.66
2	1	106.11	175.44	81.15	90.69	78.01	84.93	83.42	172.20	103.66
2	2	106.11	176.32	93.31	92.78	78.01	83.56	87.70	171.71	103.66
Average		39.42	63.59	32.94	34.05	29.28	31.99	32.40	62.34	38.56

Table 3-8. Risk ratios for RNP 10 aircraft with right offsets and a 50 NM lateral separation minimum for various intersection angles.

Offset a/c 1 (NM)	*Offset a/c 2 (NM)*	*Risk ratio*									
		θ = 5º	*θ = 15º*	*θ = 40º*	*θ = 75º*	*θ = 90º*	*θ = 110º*	*θ = 120º*	*θ = 135º*	*θ = 165º*	*θ = 175º*
0	0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
0	2	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1	0	1.33	1.34	1.35	1.34	1.33	1.35	1.35	1.35	1.33	1.33
1	1	1.33	1.34	1.35	1.35	1.33	1.34	1.35	1.35	1.33	1.33
1	2	1.33	1.34	1.35	1.34	1.33	1.34	1.35	1.35	1.33	1.33
2	0	1.76	1.78	1.82	1.80	1.77	1.81	1.82	1.82	1.78	1.76
2	1	1.76	1.78	1.82	1.81	1.77	1.81	1.82	1.82	1.78	1.76
2	2	1.76	1.78	1.82	1.80	1.77	1.81	1.82	1.82	1.78	1.76
Average		1.36	1.37	1.39	1.38	1.37	1.38	1.39	1.39	1.37	1.36

Table 3-9. Averaged collision for RNP 10 aircraft without and with right offsets and a 50 NM lateral separation minimum for various intersection angles.

Intersection angle θ (degrees)	*Averaged collision risk without offsets*	*"Averaged" collision risk with offsets*	*Intersection angle θ (degrees)*	*Averaged collision risk without offsets*	*"Averaged" collision risk with offsets*
15	1.34E-08	1.84E-08	95	1.52E-09	2.11E-09
20	8.73E-09	1.21E-08	100	1.43E-09	1.99E-09
25	5.31E-09	7.38E-09	105	1.96E-09	2.72E-09
30	2.47E-09	3.43E-09	110	1.75E-09	2.42E-09
35	1.46E-09	2.03E-09	115	1.59E-09	2.21E-09
40	1.13E-09	1.57E-09	120	1.51E-09	2.10E-09
45	8.67E-10	1.21E-09	125	1.53E-09	2.13E-09
50	8.00E-10	1.11E-09	130	1.69E-09	2.35E-09
55	7.82E-10	1.09E-09	135	2.04E-09	2.84E-09
60	8.10E-10	1.13E-09	140	2.68E-09	3.73E-09
65	8.80E-10	1.22E-09	145	3.75E-09	5.21E-09
70	1.02E-09	1.42E-09	150	5.62E-09	7.81E-09
75	1.15E-09	1.59E-09	155	8.78E-09	1.22E-08
80	1.30E-09	1.81E-09	160	1.41E-08	1.96E-08
85	1.43E-09	1.99E-09	165	2.35E-08	3.22E-08
90	1.51E-09	2.07E-09			

Chapter 4

IMPLEMENTATION CONSIDERATIONS

4.1 INTRODUCTION

4.1.1 The successful implementation of the proposed strategic lateral offset procedure 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), the *Procedures for Air Navigation Services — Air Traffic Management* (PANS-ATM, Doc 4444, 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

4.2.1 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 procedure 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, State or local operational environment, infrastructure and capability.

Step 5: 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 in accordance with appropriate safety risk management techniques as set out in the Doc 9859; and

b) regulatory approvals.

Step 6: Develop suitable safety assessment documentation and associated safety cases.

Step 7: Implement a suitable post-implementation monitoring and review processes, which should include continuous reporting and monitoring results of incidents, events and observations.

Attachment A

IMPLEMENTATION HAZARD LOG

This section lists some hazards that were considered by the SASP when developing the SLOP. 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 – Offsets to the left
Hazard Risk of collision.
Unsafe Event (cause) A pilot incorrectly offsets the aircraft to the left resulting in a collision with another aircraft operating at the wrong altitude but correctly applying the Strategic Lateral Offset Procedure.
Analysis It has been observed through extensive monitoring in the North and West Atlantic airspace that the previous Wake Turbulence Procedure is often incorrectly applied, as it provided the pilot with the option of offsetting to the left.
SASP global controls and/or mitigators Development of the SLOP circular as guidance material.
Regional and local controls and/or mitigators required 1) All incidents related to incorrect application of SLOP must be reported and investigated. 2) The appropriate authority should publish the SLOP in AIC and other applicable aeronautical documents. 3) States and operators should develop and publish awareness material. 4) Operators must train pilots to correctly apply SLOP procedures.

Subject 2 – Excessive offsets
Hazard Loss of separation.
Unsafe Event (cause) Pilot executes an offset greater than the prescribed maximum.
Analysis Pilot fails to apply proper offsets or fails to monitor aircraft navigation when establishing the offset resulting in a decrease in separation with an adjacent route or aircraft. The airspace risk is affected.
SASP global controls and/or mitigators Development of the SLOP circular as guidance material.
Regional and local controls and/or mitigators required 1) All incidents related to incorrect application of SLOP must be reported and investigated. 2) The appropriate authority should publish the SLOP in AIC and other applicable aeronautical documents. 3) States and operators should develop and publish awareness material. 4) Operators must train pilots to correctly apply SLOP procedures.

Subject 3 – Incorrect SLOP implementation
Hazard Loss of separation.
Unsafe Event (cause) The implementing authority authorizes an inappropriate application of SLOP within their airspace.
Analysis The implementing authority authorizes inappropriate offsets for the airspace. This may result in the operations in the airspace not meeting the TLS ($5x10^{-9}$ fatal accidents per flight hour).
SASP global controls and/or mitigators Development of the SLOP circular as guidance material.
Regional and local controls and/or mitigators required The implementing authority should comply with all pertinent standards, recommended practices and guidance material concerning the implementation of SLOP.

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