Twenty-Third Meeting of the
Informal South Pacific ATC Co-ordinating Group (ISPACG/23)

Santiago, Chile, 25-27 March 2009

Agenda Item 4: Review Open Action Items

THE EFFECT OF STRATEGIC LATERAL OFFSET PROCEDURES (SLOP) ON OPERATIONS IN AIRSPACE WITH 30 NM LATERAL AND 30 NM LONGITUDINAL SEPARATION STANDARDS IN PLACE

(Presented by Federal Aviation Administration)

SUMMARY

This paper provides an illustration of the effect of the Strategic Lateral Offset Procedures (SLOP) on estimate of collision risk for the 30 nautical mile (NM) longitudinal and 30 NM lateral separation standards. An increased use of SLOP allows for an overall decrease in the collision risk estimate for the 30 NM longitudinal separation standard. The use of SLOP has a negligible effect on the collision risk estimate for the 30 NM lateral separation standard for same direction aircraft. A slight increase in the 30 NM lateral collision risk estimate is observed when the opposite direction is on each pilot's right side. The beneficial decrease in the collision risk estimate obtained from the use of SLOP in the vertical and longitudinal dimensions more than compensates for the slight increase in the collision risk in the lateral dimension. This result, of course, assumes the lateral offset procedure is used in accordance with the recommended practice.

1. INTRODUCTION

1.1 At the Twenty-second Meeting of the Informal South Pacific ATC Coordinating Group (ISPACG/22), the Federal Aviation Administration (FAA) presented information on the progress in ensuring consistent SLOP procedures throughout FAA controlled international airspace (references 1 and 2).

1.2 The increased use of SLOP in oceanic and remote airspace provides safety benefits. The use of SLOP reduces the risk of collision in the vertical dimension, particularly for route systems with an alternate Flight Level Orientation Scheme (FLOS). Random distribution of aircraft on and to the right of the centerline is the key to compensating for the extremely accurate navigation capabilities of modern aircraft based on Global Positioning System (GPS) navigation. By randomly offsetting either zero (0), one (1) or two (2) NM right of the center line, SLOP significantly reduces vertical risk and also incorporates wake turbulence avoidance procedures.

1.3 The use of SLOP in airspace also affects the estimate of collision risk in the lateral and longitudinal dimensions. The purpose of this paper is to illustrate this effect in airspace with the 30 NM lateral and 30 NM longitudinal separation standards in place.

2. BACKGROUND

2.1 The ICAO Separation and Airspace Safety Panel (SASP) developed guidelines for the use of SLOP. The use of lateral offsets as a safety measure to reduce the risk of collision in the event of loss of vertical separation was the subject of State Letter AN 13/11.6-00/96 dated 3 November 2000, which provided guidelines on the subject. This first State Letter provided guidelines to allow for the use of a 1 NM offset to the right of centre line where the minimum lateral separation was 50 NM in a Required Navigation Performance (RNP) 10 non-radar environment.

2.2 The ICAO SASP reviewed the lateral offset guidelines in late 2001. The amended guidelines were the subject of State letter AN 13/11.6-02/21 dated 31 May 2002. These amended guidelines allowed for the application of offset procedures of up to 2 NM right of centre line provided that a specific safety analysis for the particular airspace had shown that the proposed procedures would meet appropriate safety criteria. The SASP continued to develop the guidelines further with the intent of eliminating the need for safety analysis by States for particular implementations of 2 NM offset procedures.

2.3 In 2004, the SASP had completed its work to provide global guidelines on the use of 2 NM lateral offsets to the right of centre line. The results of this work showed the application of 2 NM lateral offset procedures achieved greater safety benefit than 1 NM offsets and also incorporated wake turbulence procedures. The 2 NM lateral offset procedures could also be applied in airspace where the RNP 4-based 30 NM lateral separation standard was implemented. The revised guidelines are contained in ICAO State Letter AN 13/11.6-04/85 issued on 27 August 2004 (reference 3).

3. DISCUSSION

3.1 The FAA contributed to the work which assessed the effect of the use of SLOP on collision risk. Reference 4 derives formulas and presents results for estimating the probability that airplanes assigned to adjacent parallel routes will have laterally overlapping positions. An important parameter in the collision risk model, which is affected by the use of SLOP, is the lateral overlap probability.

3.2 The definitions for the lateral overlap probability parameter in the longitudinal and lateral collision risk models are provided in Table 1. We consider the effect of SLOP on airspace operations which utilize the 30 NM lateral and 30 NM longitudinal separation standards separately.

Longitudinal Collision Risk Model	Lateral overlap probability is the probability that airplanes assigned to the same route have laterally overlapping positions.
Lateral Collision Risk Model	Lateral overlap probability is the probability that airplanes assigned to adjacent parallel routes have laterally overlapping positions

Table 1. Definitions of Lateral Overlap Probability for the Longitudinal and Lateral Collision Risk Model

3.3 Effect of SLOP on Airspace Operations Utilizing the 30 NM Longitudinal Separation Standard

3.3.1 The use of SLOP in airspace affects the risk of collision due to the loss of planned longitudinal separation in a similar manner as it does in the vertical dimension. When the longitudinal separation standard is applied, the two airplanes are operating on the same track and flight level. The planned lateral separation between the airplane pair is equal to 0 NM. Both of the airplanes in the pair have the option to initiate SLOP and can elect to operate on one of the two available offset paths: the path 1 NM to the right of the center line or the path 2 NM to the right of center line.

3.3.2 The lateral navigation performance for RNP 4 airplanes eligible for the 30 NM longitudinal separation standards is modeled by a double double exponential (DDE) density function:

$$f(x;\alpha,\lambda_1,\lambda_2)=\frac{1-\alpha}{2\lambda_1}e^{\frac{-|x|}{\lambda_1}}+\frac{\alpha}{2\lambda_2}e^{\frac{-|x|}{\lambda_2}} \quad \text{where } 0<\alpha<1, \text{ and } 0<\lambda_1<\lambda_2 \qquad (1)$$

3.3.3 The DDE density function, $f(x;\alpha,\lambda_1, \lambda_2)$, is a weighted sum of two double exponential densities, a "core" density with parameter λ_1, and a "tail" density with parameter λ_2. The weights are 1-α and α; the core density, $\frac{1}{2\lambda_1}e^{\frac{-|x|}{\lambda_1}}$, describes typical lateral deviations from the centerline of the aircraft's intended route; and the tail density, $\frac{1}{2\lambda_2}e^{\frac{-|x|}{\lambda_2}}$, describes atypical lateral deviations from the centerline of the intended route. The shape parameters, λ_1 and λ_2, are respectively $\frac{\sqrt{2}}{2}$ times the standard deviations of typical lateral errors and atypical errors (reference 4). It is assumed that aircraft eligible for the 30 NM longitudinal separation standard meet level RNP 4 criteria. The requirement for RNP 4 implies that 95 percent of typical deviations lie within 4 NM of the route center line. However, data observations of RNP 4 aircraft, or aircraft equipped with GPS, show the lateral navigation performance is much better than the 4 NM requirement for containment (reference 5). Therefore, to represent the actual lateral navigation performance of these aircraft more accurately, we assume that 95 percent of typical deviations lie within 0.15 NM of the route center line. Therefore, λ_1, the parameter implied by the 95 percent containment requirement is equal to $-\frac{0.15}{\ln(0.05)}$. Then, λ_2 is the lateral distance between the routes, 30 NM, a conservative value which maximizes the probability of lateral overlap.

3.3.4 Future Air Navigation System (FANS) 1/A airplanes eligible for the 30 NM longitudinal separation standard utilize GPS as the navigation system. Therefore, the lateral deviations of both airplanes in the aircraft pair follow the same DDE density. Figure 1 provides an illustration of the possible positions of the airplanes which are following the same route utilizing SLOP when longitudinal separation is applied. The shaded grey airplanes in Figure 1 represent the possible offset locations from the route center line.

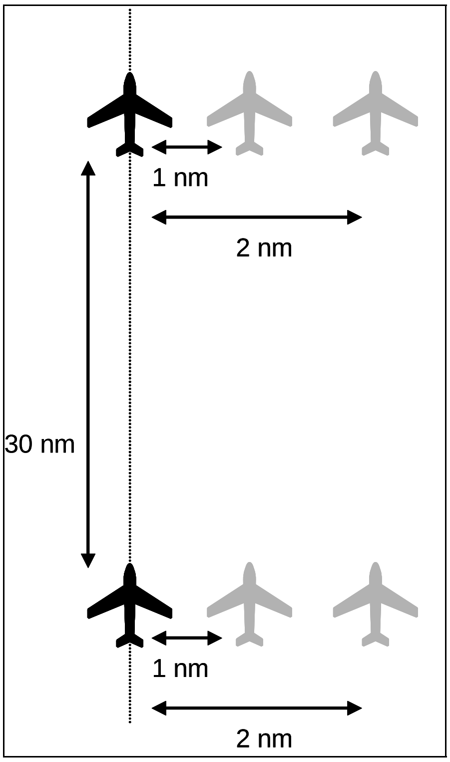

Figure 1. Illustration of the Possible SLOP Offsets for Airplanes Following the Same Track and Flight Level in Longitudinal Separation

3.3.5 The resulting probability of lateral overlap depends on the probability that a randomly chosen aircraft elects to fly an offset. The observed Automatic Dependent Surveillance –Contract (ADS-C) data from Oakland Oceanic Center show a very small proportion of operations utilize SLOP.

3.3.6 It is assumed that all airplanes eligible for the 30 NM longitudinal separation standard are capable of flying offsets. We also assume that any randomly chosen airplane has met the RNP 4, i.e. all airplanes are eligible for the reduced longitudinal separation standard. We do not consider the proportion of GPS and non-GPS operations. For illustration purposes, various proportions of operations choosing to elect an offset are examined.

3.3.7 The DDE density function in equation (1) is used to model the lateral overlap probability. The lateral overlap probability for airplanes that operate with GPS navigation systems are assumed to perform at a level equivalent to RNP 0.15 as noted in reference 4. Reference 4 (paragraph 5.4) also provides the value for α in equation (1) for GPS airplanes as 4.8 x 10^{-5}. Table 2 and Figure 2 present these results.

3.3.8 The unmodified lateral overlap probability provided in Table 2 corresponds to the lateral displacement of 0 NM (e.g. flying on route center line), and offsets to the right of center line of either 1 or 2 NM. The probability of lateral displacement shown in Table 2 represents the proportion of airplanes that elect to fly on center line and those choosing an offset. There are many possible values for the probability that an individual aircraft chooses to fly an offset. One possible combination is shown in Table 2; this combination represents an even mix amongst the three possible choices for applying SLOP. In Table 2, the proportion of airplanes electing to fly on route center line is shown as 34 percent, and the proportions of airplanes electing to fly offsets of 1 NM and 2 NM are both 33 percent. Figure 2 shows the overall lateral overlap probability result for the possible lateral displacement combinations. The data shown in Figure 2 begins with 100 percent of the airplanes flying on route center line and ends with the even mix proportion shown in Table 2 where 34 percent of the airplanes fly on route centerline.

RNP Equivalent (for GPS Airplanes)	0.15		
α	4.08E-05		
λ_1	0.0500712		
λ_2	30		
λ_y	0.0321		
Lateral Displacement	**Unmodified Lateral Overlap Probability ($P_y(S)$)**	**Probability of Lateral Displacement**	**Resulting Probability of Lateral Overlap**
0	3.205E-01	0.34	0.1090
1	9.870E-08	0.33	3.257E-08
2	8.168E-08	0.33	2.695E-08
			0.10898

Table 2. The Effect of SLOP on the Lateral Overlap Probabilities for the 30 NM Longitudinal Separation Standard

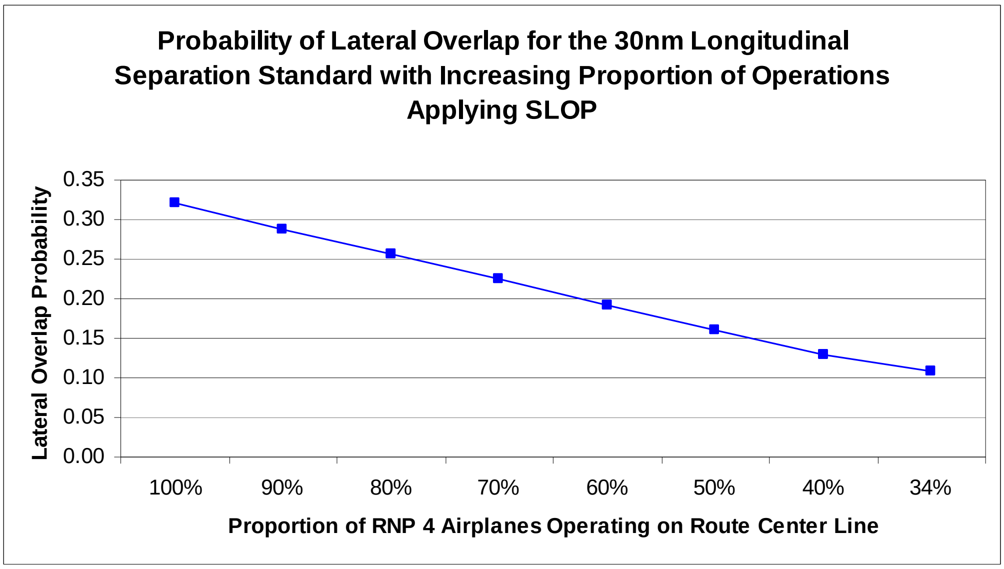

Figure 2. Probability of Lateral Overlap with an Increasing Proportion of Operations Applying SLOP for the 30 NM Longitudinal Separation Standard

3.3.9 The results provided in Table 2 and Figure 2 show that an increased use of SLOP relates to a lower lateral overlap probability in airspace where GPS airplanes operate. These results show that in the event a longitudinal overtake occurs, the chance that the airplanes are in lateral overlap decreases with the use of SLOP. The overall percent decrease in the lateral overlap probability ranges from 10 to 66 percent of the lateral overlap probability associated with all aircraft flying on route center line.

3.4 Effect of SLOP on Airspace Operations Utilizing the 30 NM Lateral Separation Standard for Same Direction Routes

3.4.1 When utilizing SLOP, the actual lateral separations between airplanes operating on same direction routes separated laterally by 30 NM ranges from 28 NM through 32 NM. The direction of the lateral displacement from route center line is to the pilot's right side, either 1 NM or 2 NM off route center line. The smallest lateral separation occurs when the airplane operating on the route located on the left side elects an offset 2 NM from route center line and the airplane operating on the route located on the right side chooses not to offset and operates on route center line. Figure 3 shows the possible lateral separation between aircraft for same direction routes with 30 NM lateral spacing. The shaded grey airplanes in Figure 3 represent the possible offsets locations from route center line.

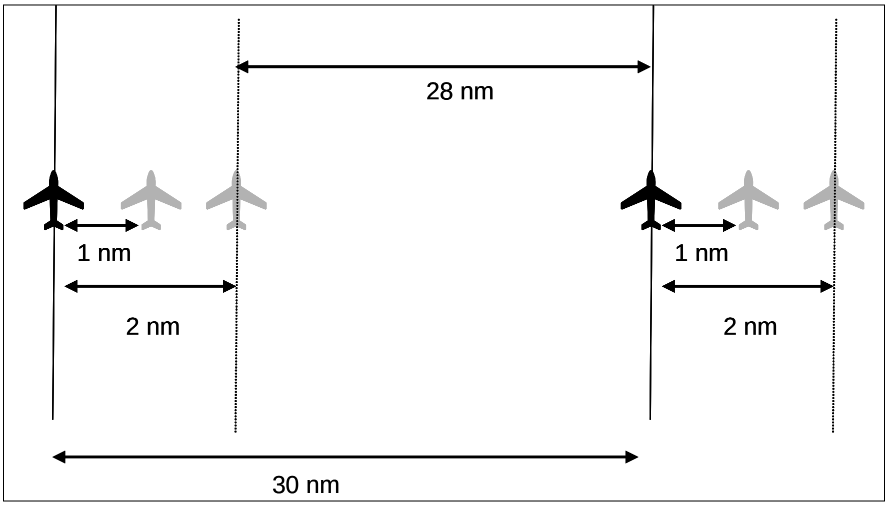

Figure 3. Illustration of the Possible SLOP Offsets for Airplanes Traveling on Same Direction Adjacent Routes Separated by 30 NM

3.4.2 It is assumed that all airplanes eligible for the 30 NM lateral separation standard are capable of flying offsets. We also assume that any randomly chosen airplane has met the RNP 4, i.e. all airplanes are eligible for the reduced lateral separation standard. It is assumed the airplanes on these routes all use GPS for navigation. We do not consider the proportion of GPS and non-GPS operations. For illustration purposes, various proportions of operations choosing to elect an offset are examined.

3.4.3 The DDE density function in equation (1) is used to model the lateral overlap probability. The lateral overlap probability for airplanes that operate with GPS navigation systems are assumed to perform at a level equivalent to Required Navigation Performance (RNP) 0.15 as noted in reference 4. Reference 4 (paragraph 5.4) also provides the value for α in equation (1) for GPS airplanes as 4.8×10^{-5}.

3.4.4 The probability of each possible lateral separation distance between a pair of airplanes under SLOP depends on the likelihood that a pilot elects to fly an offset. Under SLOP, the possible lateral separation distances are S_y, S_y+1, S_y+2, S_y-1, and S_y-2, where S_y is the nominal lateral separation between the routes, in the case of the 30 NM lateral separation standard, S_y is equal to 30 NM.

3.4.5 Consistent with the same notation found in reference 4, we imagine that from our viewpoint the traffic on the two parallel adjacent routes is moving away from us, so that it makes sense to refer to a “left” route and a “right” route. Let L be the intended offset of the airplane chosen from the left route, and R be the intended offset of the airplane chosen from the right route. To compute the probability that the intended separation between a randomly chosen pair of airplanes is 30 NM, both airplanes would have chosen to fly the route center line or the same lateral offset, e.g. the individual lateral displacement from route center line would be the same for both airplanes, P(L=0, R=0) + P(L=1, R=1) + P(L=2, R=2).

3.4.6 In addition, the probability that the lateral separation between a randomly chosen pair of airplanes is equal to 28 NM is equal to P(L=2,R=0). Table 3 contains a complete list of all possible combinations for the system of two parallel routes carrying same direction traffic.

Lateral Separation Distance with the Application of SLOP (NM)	Corresponding Probability
28	P(L=2, R=0)
29	P(L=1, R=0) + P(L=2, R=1)
30	P(L=0, R=0) + P(L=1, R=1) + P(L=2, R=2)
31	P(L=0, R=1) + P(L=1, R=2)
32	P(L=0, R=2)

Table 3. Lateral Separation Distances and the Corresponding Probabilities with the Use of SLOP for Same Direction Routes with 30 NM Lateral Spacing

3.4.7 Table 4 and Figure 4 present the results showing the effect of SLOP on the 30 NM lateral separation standard for same direction routes. There are many possible values for the probability that a randomly chosen airplane elects an offset. For illustration purposes we show a range of possible values in Figure 4. One possible combination is shown in Table 4; this combination represents an even mix amongst the three possible choices for applying SLOP. In Table 4, the proportion of airplanes electing to fly on route center line is shown as 34 percent, and the proportions of airplanes electing to fly offsets of 1 NM and 2 NM are both 33 percent. Figure 4 shows the overall lateral overlap probability result for the possible lateral displacement combinations. The data shown in Figure 4 begins with 100 percent of the airplanes flying on route center line and ends with the even mix of airplanes applying offsets where 34 percent of the airplanes operate on route centerline.

RNP Equivalent (for GPS Airplanes)	0.15
α	4.08E-05
λ_1	0.0500712
λ_2	30
λ_y	0.0321

P(offset=0)	0.34
P(offset=1)	0.33
P(offset=2)	0.33

Lateral Displacement	**Unmodified Lateral Overlap Probability ($P_y(S)$)**	**Probability of Lateral Displacement**	**Resulting Probability of Lateral Overlap**
28	3.433E-08	0.1122	3.852E-09
29	3.321E-08	0.2211	7.342E-09
30	3.212E-08	0.3334	1.071E-08
31	3.107E-08	0.2211	6.869E-09
32	3.005E-08	0.1122	3.371E-09
			3.214E-08

Table 4. The Effect of SLOP on the Lateral Overlap Probabilities for Routes with Same Direction Traffic for the 30 NM Lateral Separation Standard

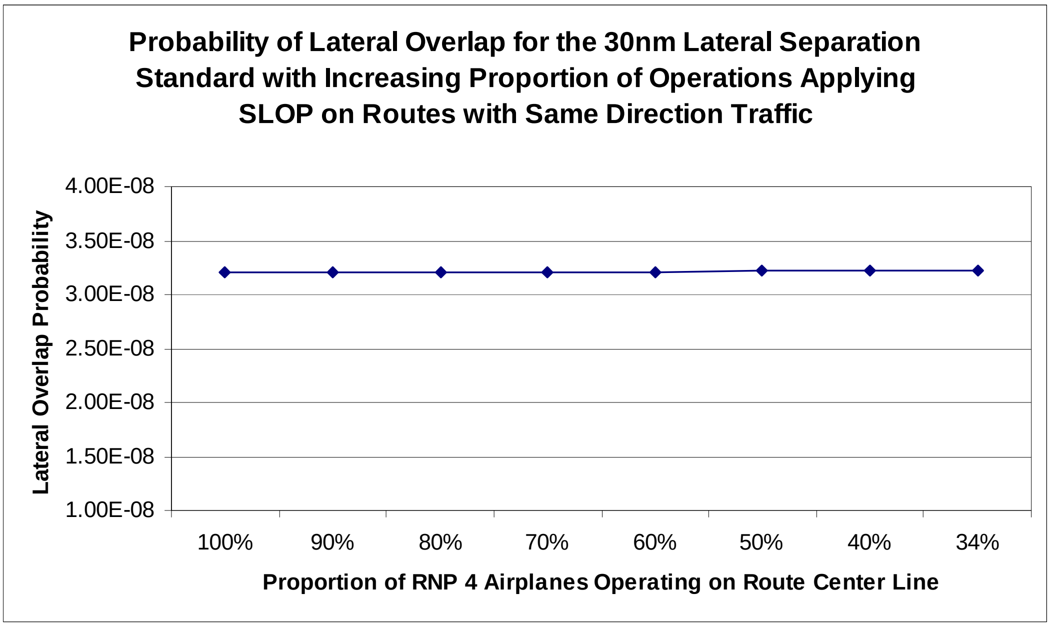

Figure 4. Probability of Lateral Overlap for the 30 NM Lateral Separation Standard for Routes with Same Direction Traffic with an Increasing Proportion of Operations Applying SLOP

3.4.8 The results provided in Table 4 and Figure 4 show that an increased use of SLOP on routes with same direction traffic relates to a negligible increase in lateral overlap probability in airspace where GPS airplanes operate. The overall percent increase in the lateral overlap probability ranges from 0.03 to 0.07 percent of the lateral overlap probability associated with all aircraft flying on route center line. One reason for the minimum impact on the lateral overlap probability for the 30 NM lateral separation standard for routes with same direction traffic is under SLOP the chance that the pair of airplanes are actually separated by 30 NM is higher than all other possible lateral separations.

3.5 Effect of SLOP on Airspace Operations Utilizing the 30 NM Lateral Separation Standard for Routes with Opposite Direction Traffic on Each Pilot's Right

3.5.1 When applying SLOP, the actual lateral separations between airplanes operating on routes separated by 30 NM with the opposite direction route on each pilot's right, ranges from 26 NM through 30 NM. The direction of the lateral displacement is to the pilot's right side, either 1 NM or 2 NM from route center line. The smallest lateral separation occurs when the airplane operating on the route located on the left side elects an offset 2 NM from route center line and the airplane operating on the route located on the right side also elects an offset 2 NM to the right of route center line. Figure 6 shows the possible lateral separation between aircraft on parallel routes where the opposite direction is on each pilot's right side. The shaded grey airplanes in Figure 6 represent the possible offset positions from route center line.

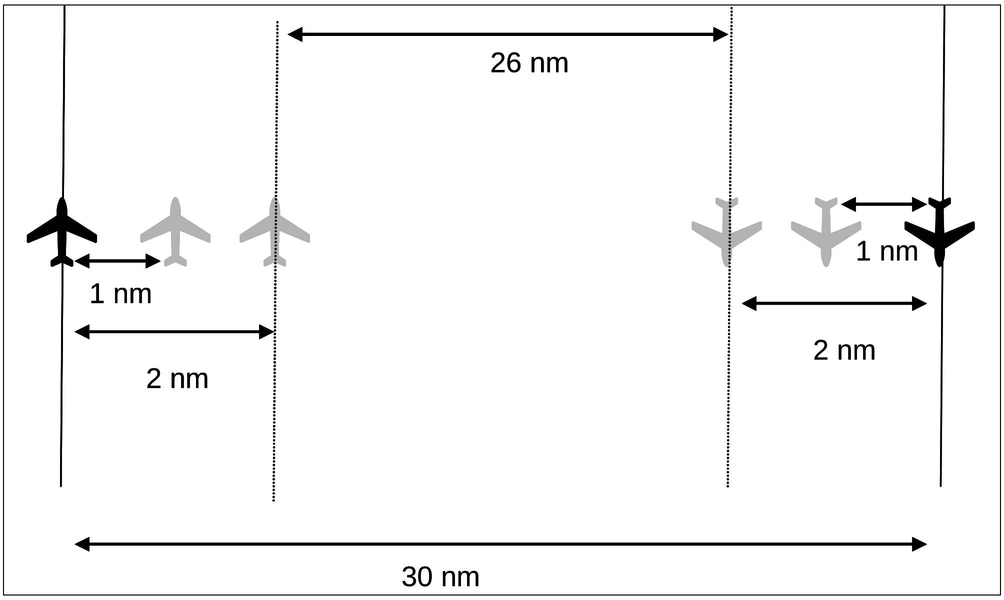

Figure 6. Illustration of the Possible SLOP Offsets for Airplanes Traveling in Opposite Directions on Routes Separated by 30 NM (Where the Opposite Direction Route is on Each Pilot's Right)

3.5.2 Again, it is assumed that all airplanes eligible for the 30 NM lateral separation standard are capable of flying offsets. We also assume that any randomly chosen airplane has met the RNP 4, e.g. all airplanes are eligible for the reduced lateral separation standard. It is assumed the airplanes on these routes all use GPS for navigation. We do not consider the proportion of GPS and non-GPS operations. For illustration purposes, various proportions of operations choosing to elect an offset are examined.

3.5.3 The DDE density function in equation (1) is used to model the lateral overlap probability. The lateral overlap probability for airplanes that operate with GPS navigation systems are assumed to perform at a level equivalent to RNP 0.15 as in reference 4. Reference 4 (paragraph 5.4) also provides the value for α in equation (1) for GPS airplanes as 4.8×10^{-5}.

3.5.4 The probability of each possible lateral separation distance between a pair of airplanes depends on the likelihood that a pilot elects to fly an offset. Under SLOP, the possible lateral separation distances are S_y, S_y-1, S_y-2, S_y-3, and S_y-4, where S_y is the nominal lateral separation between the routes, in the case of the 30 NM lateral separation standard, S_y is equal to 30 NM.

3.5.5 Consistent with the same notation found in reference 4, we imagine that from our viewpoint the traffic on the left route is moving away from us, and the traffic on the right route is moving toward us. Again we let L be the intended offset of the airplane chosen from the left route, and R be the intended offset of the airplane chosen from the right route. To compute the probability that the intended separation between a randomly chosen pair of airplanes is 30 NM, both airplanes would have chosen to fly the route center line, P(L=0, R=0).

3.5.6 In addition, the probability that the lateral separation between a randomly chosen pair of airplanes is equal to 26 NM is equal to P(L=2, R=2). Table 5 contains a complete list of all possible combinations for the system of two parallel routes carrying opposite direction traffic where the opposite direction route is on each pilot's right.

Lateral Separation Distance with the Application of SLOP (NM)	Corresponding Probability
26	P(L=2, R=2)
27	P(L=1, R=2) + P(L=2, R=1)
28	P(L=0, R=2) + P(L=2, R=0) + P(L=1, R=1)
29	P(L=0, R=1) + P(L=1, R=0)
30	P(L=0, R=0)

Table 5. Lateral Separation Distances and the Corresponding Probabilities with the Use of SLOP for Opposite Direction Routes with 30 NM Lateral Spacing and the Opposite Direction Traffic is on Each Pilot's Right

3.5.7 Table 6 and Figure 6 present the results showing the effect of SLOP on the 30 NM lateral separation standard where the opposite direction traffic is on each pilot's right. There are many possible values for the probability that a randomly chosen airplane elects an offset. For illustration purposes we show a range of possible values. One possible combination is shown in Table 6; this combination represents an even mix amongst the three possible choices for applying SLOP. In Table 6, the proportion of airplanes electing to fly on route center line is shown as 34 percent, and the proportions of airplanes electing to fly offsets of 1 NM and 2 NM are both 33 percent. Figure 6 shows the overall lateral overlap probability result for the possible lateral displacement combinations. The data shown in Figure 6 begins with 100 percent of the airplanes flying on route center line and ends with the even mix of airplanes applying offsets where 34 percent of the airplanes operate on route centerline.

RNP Equivalent (for GPS Airplanes)	0.15
α	4.08E-05
λ_1	0.0500712
λ_2	30
λ_y	0.0321

P(offset=0)	0.34
P(offset=1)	0.33
P(offset=2)	0.33

Lateral Displacement	Unmodified Lateral Overlap Probability ($P_y(S)$)	Displacement Probability	Resulting Probability of Lateral Overlap
26	3.670E-08	0.1089	3.997E-09
27	3.550E-08	0.2178	7.731E-09
28	3.433E-08	0.3333	1.144E-08
29	3.321E-08	0.2244	7.452E-09
30	3.212E-08	0.1156	3.713E-09
			3.434E-08

Table 6. The Effect of SLOP on the Lateral Overlap Probabilities for Routes with Opposite Direction Traffic Where the Opposite Direction Traffic is on Each Pilot's Right

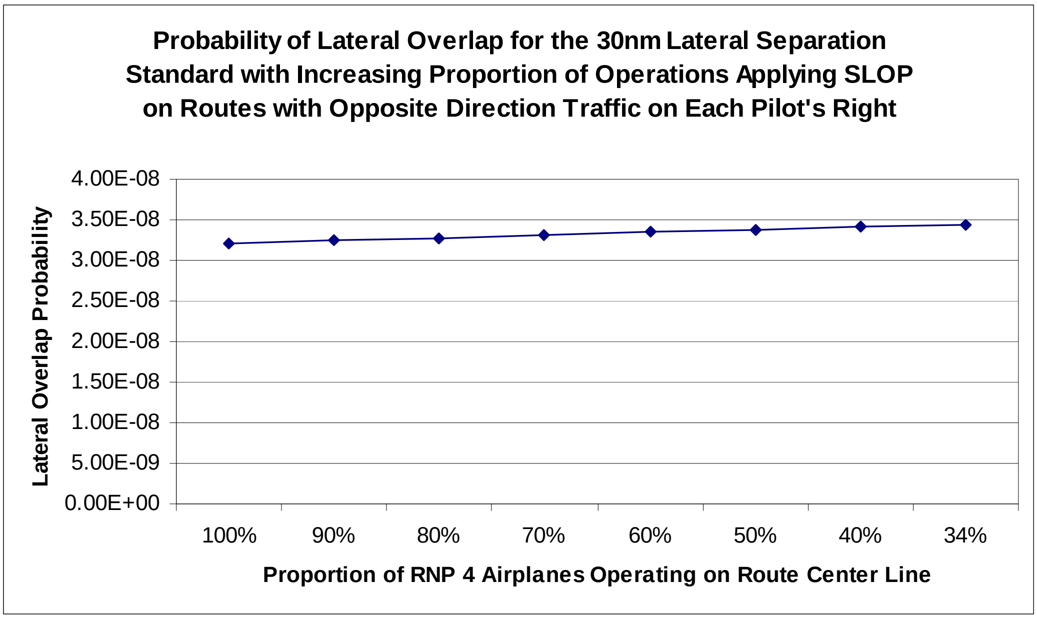

Figure 6. Probability of Lateral Overlap for the 30 NM Lateral Separation Standard for Routes with Opposite Direction Traffic on Each Pilot's Right with an Increasing Proportion of Operations Applying SLOP

3.5.8 The results provided in Table 6 and Figure 6 show that an increased use of SLOP relates to a slightly elevated lateral overlap probability for routes with the opposite direction route on each pilot's right side. The overall percent increase in the lateral overlap probability ranges from 1.03 to 6.90 percent of the lateral overlap probability associated with all aircraft flying on route center line.

3.6 The resulting beneficial decrease in the collision risk estimate in the vertical and longitudinal dimensions from the use of SLOP more than compensates for the slight increase in the collision risk estimate resulting from the use of SLOP in the lateral dimension. This result, of course, assumes the lateral offset procedure is used in accordance with the recommended practice.

4. ACTION BY THE MEETING

4.1 The meeting is invited to note the information provided.

REFERENCES

1 "Strategic Lateral Offset Procedures (SLOP) in FAA Oceanic Airspace", ISPACG/22, WP/8, 12-14 March 2008, Papeete, Tahiti.

2 "Summary of Discussion of the Twenty Second Meeting of the Informal South Pacific Air Traffic Services Co-ordinating Group (ISPACG/22)", 12-14 March 2008, Papeete, Tahiti.

3 *Revised Guidelines on the Use of Strategic Lateral Offsets*, ICAO State letter AN 13/11.6-04/85, 27 August 2004.

4 Flax, Bennett, "Lateral Overlap Probabilities in Route Systems Where Lateral Offsets are Applied", WP/5, ICAO Separation and Airspace Safety Panel (SASP), First Meeting of the Working Group of the Whole (WG/WHL/1), Canberra, Australia, May 2002.

5 Gerhardt-Falk, C., Martin, L., Ellis, S., "Correlation of Airborne Position Estimates to Ground Based Independent Estimates and Deviations from Flight-Planned Tracks," American Institute of Aeronautics and Astronautics (AIAA) Guidance, Navigation, and Control Conference, Hilton Head, South Carolina, USA, August 20-23, 2007 (AIAA 2007-6520 - Invited Session).