Table E-6. Top 21 operator/aircraft type combinations observed in combined December 2007 TSD

Pair Number	*Operator-Aircraft Type*	*Count*	*Proportion*	*Cumulative Count*	*Cumulative Proportion*
1	SIA-B772	611	0.1064	611	0.1064
2	AXM-A320	439	0.0764	1050	0.1828
3	CPA-A333	336	0.0585	1386	0.2413
4	TGW-A320	327	0.0569	1713	0.2983
5	SIA-B773	312	0.0543	2025	0.3526
6	CPA-B773	245	0.0427	2270	0.3953
7	MAS-A333	193	0.0336	2463	0.4289
8	CXA-B737	144	0.0251	2607	0.4539
9	SQC-B744	139	0.0242	2746	0.4781
10	JSA-A320	125	0.0218	2871	0.4999
11	CES-A333	124	0.0216	2995	0.5215
12	CES-A319	122	0.0212	3117	0.5427
13	SIA-B744	122	0.0212	3239	0.5640
14	CSN-A320	103	0.0179	3342	0.5819
15	MAS-B772	103	0.0179	3445	0.5999
16	UAL-B744	99	0.0172	3544	0.6171
17	CSN-A319	99	0.0172	3643	0.6343
18	CSZ-B738	97	0.0169	3740	0.6512
19	CPA-B772	95	0.0165	3835	0.6678
20	SLK-A319	93	0.0162	3928	0.6840
21	GIA-B738	92	0.0160	4020	0.7000

Appendix F

OVERVIEW OF PERFORMANCE-BASED HORIZONTAL COLLISION RISK MODELLING ASSUMPTIONS

The purpose of this appendix is to summarize the collision risk modeling assumptions used in the development of the performance-based horizontal separation minima established for oceanic and remote continental navigation applications.

F.1 LONGITUDINAL COLLISION RISK MODEL

F.1.1 General

F.1.1.1 The longitudinal model developed for the distance-based separation minima in a required navigation performance (RNP) area navigation (RNAV) environment using an automatic dependent surveillance – contract (ADS-C) and lateral separation of aircraft on parallel or non-intersecting tracks or air traffic services (ATS) routes defined is:

$$CR(t_0,t_1)=2NP\int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{t_0}^{t_1}HOP(t\,|\,V_1,V_2)P_z(h_z)\left(\frac{2V_{rel}}{\pi\lambda_{xy}}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right)f_1(V_1)f_2(V_2)\,dt\,dV_1\,dV_2 \qquad (1)$$

F.1.1.2 The horizontal overlap probability (HOP) term in equation (1) considers the along-track and cross-track position errors of two longitudinally separated aircraft. An equation for operations on the same identical track (e.g. angle of zero degrees) is given in Doc 9689, Appendix 1 as:

$$HOP(t\,|\,V_1V_2)=\frac{\pi\lambda_{xy}^2}{16\lambda^2}e^{-|D_x(t)|/\lambda}\left(\frac{|D_x(t)|}{\lambda}+1\right) \qquad (2)$$

F.1.1.3 In equation (2), Dx(t) is the distance between the two aircraft and λ is the scale parameter of the along-track and cross-track error distributions. The along-track and cross-track errors are assumed to follow a double exponential (DE) distribution. See the navigation performance section below for more details.

F.1.1.4 Key parameters for this model are listed in Table F-1*.

* All tables are located at the end of this appendix.

F.1.2 Controller intervention buffer

F.1.2.1 *ATC-to-pilot communication times*

F.1.2.1.1 There are assumed transaction times for ATC-to-pilot messages in the distance-based longitudinal collision risk model. The message transaction times associated with each type of communication — controller-pilot data link communication (CPDLC) and high frequency (HF) as part of the controller intervention buffer, are as follows:

F.1.2.1.2 The time allocated for a CPDLC uplink transaction is 90 seconds.

F.1.2.1.3 The time allocated for the controller to wait for the CPDLC response from the pilot is 90 seconds.

F.1.2.1.4 The time allocated for ATC to use HF communication to deliver the clearance message is 300 seconds.

F.1.2.1.5 The time allocated for ATC to wait for an ADS-C or waypoint change event report is 180 seconds; if the report is not received within 180 seconds of the time it should have been sent, the report is considered overdue.

F.1.2.1.6 Data link performance data from the appropriate data link Central Reporting Agencies (CRAs), future air navigation system (FANS) Interoperability Team (FIT), NAT Data Link Monitoring Agency (DLMA), or air navigation services providers (ANSPs) should be monitored and utilized to ensure that the communication performance meets these assumptions prior to implementation. Post-implementation monitoring activities should include periodic checks on the communication performance to ensure that the assumptions continue to be valid for the airspace. The observed communication performance may be substituted in place of the assumed performance to obtain an estimate of risk specific to the airspace.

F.1.2.2 *Controller intervention buffer scenarios*

F.1.2.2.1 The longitudinal distance-based collision risk model developed for an RNP RNAV environment using automatic dependent surveillance (ADS) includes a controller intervention buffer. This is the time to allow a controller to intervene and resolve a potential conflict by contacting an aircraft using the available communication systems. The collision risk modeling considered three cases, as described in Doc 9689, Appendix 8: normal operation, pilot response to CPDLC is not received requiring HF communication, and ADS-C or waypoint change event report is overdue.

F.1.2.2.2 In Case 1, normal operations, the controller intervention buffer time is 240 seconds or 4 minutes. Should the normal means of communication fail, Case 2 provides an additional 6.5 minutes using alternative means of communication for controller intervention. If a report is not received within 6 minutes from the time the original report should have been sent, Case 3 provides a total of 13.5 minutes for the conflict to be resolved.

F.1.2.2.3 The collision risk model parameter used to indicate the controller intervention buffer is τ. The three cases considered for τ; — normal ADS operation, pilot response to CPDLC is not received requiring HF communication, and ADS-C periodic report is overdue, are detailed in Tables F-2 through F-4.

F.1.2.2.4 The collision risk calculations were carried out assuming that an ADS-C or waypoint change event report is overdue 5 per cent of the time (Case 3). When ADS or waypoint change event reports are received within 3 minutes, the CPDLC response will take longer than three minutes 5 per cent of the time (Case 2). It was also assumed that normal operations occur 95 per cent of the time (Case 1). The 5 per cent lateness allowance was considered to be very conservative. The weighted risk estimates based on the 3 cases is:

$$\text{weighted risk} = 0.95 \times \left(0.95 \times \text{risk}(\tau = 4) + 0.05 \times \text{risk}(\tau = 10.5)\right) + 0.05 \times \text{risk}(\tau = 13.5) \qquad (3)$$

F.1.2.2.5 The proportions in the weighted risk may be modified based on the observed performance in the airspace. Additional cases can also be included in the weighted risk equation for use in a safety assessment to account for the risk associated with specific large longitudinal events (LLEs); care must be taken to ensure the individual proportions add up to 1.

F.1.3 Navigation performance

F.1.3.1 Use of the observed navigation performance (ONP) for longitudinal risk estimation is considered to be conservative due to the highly accurate results obtained from the use of global navigation satellite system (GNSS). However, the collision risk models originally developed to support the distance-based longitudinal separation minima use the RNP specification, and not an observed navigation performance to model the lateral path keeping performance.

F.1.3.2 The accurate position estimates from GNSS produce smaller lateral errors from course and lower across track velocities. Smaller lateral errors produce higher values of lateral overlap probability, thus increasing the risk of collision in the event that airplanes lose their assigned longitudinal separation. This *navigation paradox* — improvements in navigation in one dimension, increase collision risk in another — is well known. Its presence in the application of a reduced longitudinal separation minimum is evident in the risk estimates.

F.1.3.3 A DE distribution is used to model the along-track and cross-track position errors in the distance-based longitudinal collision risk model. The observed navigation performance for GNSS aircraft has been modeled with various scale parameters, λ. For example, k = 0.05, 0.1, 0.3, 0.5, 1 and 2 have been employed to compute $\lambda = -\frac{k}{\ln(0.05)}$. The parameter λ is chosen to satisfy the requirement $\int_{-\infty}^{\infty} f(y)dy = 0.95$, which states that these RNP aircraft are expected to have position errors less than k NM in magnitude during 95 per cent of their flight time. The value for k is chosen to be lower than the RNP specification due to the very accurate GNSS positions.

F.1.4 Variation in aircraft speed

F.1.4.1 The longitudinal distance-based collision risk model developed for an RNP RNAV environment using ADS accounts for variation in aircraft speed during a time period. This time period is the time between consecutive position reports and the time allotted for the controller intervention buffer.

F.1.4.2 The speed variation follows a DE distribution with scale parameter λv = 5.82 knots. The assumed average aircraft ground speed of 480 knots is used as the location parameter, Vo. The DE distribution is truncated at 100 knots on either side of the location parameter, 480 knots, and then normalized to equal 1.

$$f_{DE}(V) = \frac{1}{2\lambda_v} e^{-\frac{|V-V_O|}{\lambda_v}} \text{ for } -100 < V < 100 \qquad (4)$$

F.1.4.3 The empirical speed variations can be observed in the airspace and used to modify the scale parameter, location parameter or truncation limits. Care must be taken to ensure that the resulting speed variation distribution is suitable for all the appropriate time periods. The time period is equal to the aircraft reporting period plus the allotted time for the controller intervention buffer. It is possible to have multiple aircraft speed variation distributions for use in the collision risk modeling as aircraft speed can be expected to vary greatly over long time periods.

F.2 LATERAL COLLISION RISK MODEL

F.2.1 General

F.2.1.1 The form of the lateral collision risk model applicable to assessing the risk, N_{ay}, of a 30 NM lateral separation standard as per Doc 9689, Appendix 15 is:

$$N_{ay} = P_y(S_y)P_z(0)\frac{\lambda_x}{S_x}\left\{E_y(same)\left[\frac{\overline{|\dot{x}|}}{2\lambda_x}+\frac{\overline{|\dot{y}(S_y)|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]+E_y(opp)\left[\frac{\overline{|V|}}{\lambda_x}+\frac{\overline{|\dot{y}(S_y)|}}{2\lambda_y}+\frac{\overline{|\dot{z}|}}{2\lambda_z}\right]\right\} \quad (5)$$

F.2.1.2 The individual parameters of the lateral collision risk model and their definitions are given in Table F-5.

F.2.1.3 Some of the parameters listed in Table F-5 are common to both the lateral and longitudinal collision risk models.

F.2.2 Lateral path keeping performance, $P_y(S_y)$

F.2.2.1 The RNP specification combined with reports of gross lateral errors (if available) provide a conservative estimate of the lateral overlap probability, $P_y(S_y)$.

F.2.2.2 The typical and atypical lateral deviations are modeled with fcore(y) and ftail(y), respectively. The overall density function of the lateral deviations is modeled by the mixture f(y) = (1-α) fcore(y)+ α ftail(y), with α as the rate of atypical deviations.

F.2.2.3 The choice of a DE distribution for the distribution ftail(y) of atypical deviations and fcore(y) is considered to be conservative. The density fDE associated with a DE distribution is given by:

$$f_{DE}(y) = \frac{1}{2\lambda}e^{-\frac{|y|}{\lambda}} \text{ for } -\infty < y < \infty \quad (6)$$

F.2.2.4 The typical lateral deviations for RNP k (for example RNP 4, where k = 4) are modeled as:

$$f(y) = \frac{1}{2\lambda}e^{-\frac{|y|}{\lambda}} \text{ with } \lambda = -\frac{k}{\ln(0.05)} \quad (7)$$

F.2.2.5 The parameter λ is chosen to satisfy the requirement $\int_{-\infty}^{\infty} f(y)dy = 0.95$, which states that RNP k aircraft are expected to have position errors less than k NM in magnitude during 95 per cent of their flight time.

F.2.3 Average absolute relative along-track speed of two aircraft, $\overline{|\dot{x}|}$

F.2.3.1 Aircraft operations on parallel tracks are independent of application of Mach number technique or any other actions by ATC to regulate the relative speed between aircraft. As a result, the relative speed between a typical pair of co-altitude aircraft on adjacent tracks reflects the range of speeds of individual aircraft in the airspace.

F.2.3.2 The reported ground speeds can be examined from the ADS-C basic reports. Using the uncorrelated-speed property of aircraft assigned to the same flight level on parallel routes, the absolute value of each possible difference in speed can be weighted according to the proportions of entries.

F.2.4 Average absolute relative cross-track speed between aircraft pairs operating on tracks nominally separated by S_y - $\overline{|\dot{y}(S_y)|}$

This parameter describes the relative speed of two aircraft as they lose all planned lateral separation. Since the basic track-keeping accuracy of aircraft equipped with navigation systems using GNSS-derived positioning is widely regarded as precluding the loss of 30 NM lateral separation due to normal navigational performance, the most reasonable circumstance associated with an event is a waypoint insertion error. There are safeguards against the occurrence of this type of event, such as the establishment of a 5 NM lateral deviation event contract for all aircraft capable of participating in the application of the 30 NM separation minimum. For example, a value of 36 knots corresponds to the lateral speed of an aircraft relative to correct track, which would result in a lateral error of 30 NM between two consecutive waypoints separated by a typical distance of 400 NM. The assumed average aircraft speed used was 480 knots.

F.2.5 Same and opposite direction lateral occupancy – E_y(same) and E_y(opp)

F.2.5.1 Occupancy is a measure of exposure of aircraft to one another. While occupancy does generally increase as traffic level increases, there is not a one-to-one correspondence between a measure of traffic activity — number of annual flights, for example — and the value of airspace occupancy. Rather, occupancy increases as more aircraft operate at the same time on the laterally adjacent flight paths, increasing the chance that there might be a proximate aircraft.

F.2.5.2 Occupancy is a dimensionless number, computed, in the lateral case, as twice the ratio of the number of aircraft on a track which are within an arbitrary longitudinal sampling interval of a typical aircraft on a laterally adjacent track. Lateral occupancy is estimated separately for aircraft flows operating in the same direction on each of two parallel tracks and for flows operating on reciprocal headings on the tracks — hence the terms *same-direction* and *opposite-direction* lateral occupancies.

F.2.5.3 The lateral occupancy can be estimated from traffic movement data. A lateral pair is identified using an aircraft position report when another aircraft crosses over the adjacent fix located on a parallel route separated by the lateral separation minimum.

TABLES FOR APPENDIX F

Table F-1. Distance-based longitudinal risk model – key parameters

Parameter	*Description*	*Units*	*Default Value*
λv	Scale parameter for the aircraft speed distribution, represents the speed decay	Knots	5.82
Vm	Maximum speed variation allowed	Knots	100
S_x	Longitudinal separation standard	NM	30, 50
RNP	Required navigation performance type	NM	4
ONP	Observed navigation performance	NM	
τ	Controller intervention buffer, response time	Seconds	240 for normal cases, 630 and 810 for abnormal cases
T	Aircraft position report interval, ADS-C periodic report rate	Minutes	10, 14, 27
V_1,V_2	Nominal aircraft speeds	Knots	480
$\overline{\lvert \dot{z} \rvert}$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation (e.g. vertical speed variation)	Knots	1.5
$P_z(0)$	Probability that two aircraft which are nominally at the same flight level are in vertical overlap		0.55
λ_{xy}	Aircraft wingspan or length	NM	
λz	Aircraft height	NM	
NP	Number of pairs that require controller intervention per flight hour	Per flight hour	

Table F-2. Components of τ for normal ADS operations

Component	*Value (seconds)*
Screen update time/controller conflict recognition	30
Controller message composition	15
CPDLC uplink	90
Pilot reaction	30
Aircraft inertia plus climb	75
Total	240

Table F-3. Components of τ when response to CPDLC uplink is not received requiring HF communication

Component	*Value (seconds)*
Screen update time/controller conflict recognition	30
Controller message composition	15
CPDLC uplink and wait for response	180
HF communication	300
Pilot reaction	30
Aircraft inertia plus climb	75
Total	630

Table F-4. Components of τ when ADS-C periodic report takes longer than 3 minutes

Component	*Value (seconds)*
Controller wait for ADS report	180
Controller message composition	15
CPDLC uplink and wait for response	180
HF communication	300
Pilot reaction	30
Aircraft inertia plus climb	75
Extra allowance	30
Total	810

Table F-5. Lateral collision risk model – key parameters

Parameter	*Description*	*Units*	*Default Value*
S_y	Lateral Separation Standard	NM	30, 50
RNP	Required Navigation Performance Type	NM	4, 10
$\overline{\lvert\dot{z}\rvert}$	Average absolute relative vertical speed of an aircraft pair that have lost all vertical separation (e.g. vertical speed variation)	Knots	1.5
Pz(0)	Probability that two aircraft which are nominally at the same flight level are in vertical overlap		0.55
$P_y(S_y)$	Probability that two aircraft which are nominally separated by the lateral separation minimum are in lateral overlap		Determined from the RNP requirement and the observed frequency of lateral errors in the airspace
λ_x	Aircraft length	NM	
λ_y	Aircraft wingspan	NM	
λ_z	Aircraft height	NM	
E_y(same)	Same direction lateral occupancy		
E_y(opp)	Opposite direction lateral occupancy		
S_x	Length of longitudinal window used to calculate occupancy	Minutes	15
$\overline{\lvert V\rvert}$	Average absolute aircraft speed	Knots	480
$\overline{\lvert\dot{y}(S_y)\rvert}$	Average absolute relative cross-track speed	Knots	
$\overline{\lvert\dot{x}\rvert}$	Average absolute relative along-track speed between aircraft on same direction routes	Knots	

Appendix G

SAMPLE SAFETY ASSESSMENT — SOUTH CHINA SEA COLLISION RISK MODEL AND SAFETY ASSESSMENT

G.1 INTRODUCTION

G.1.1 The South East Asia Safety Monitoring Agency (SEASMA), an En-route Monitoring Agency (EMA), is responsible for supporting continued safe use of the six major air traffic service routes in South China Sea international airspace. This support consists of discharging the EMA duties listed in the *Asia/Pacific Region En-Route Monitoring Agency (EMA) Handbook*.

G.1.2 The purpose of this appendix is to present an example of a safety assessment, as conducted by SEASMA on the six major South China Sea routes, together with the collision risk model used, to assess compliance with APANPIRG-agreed Target Level of Safety (TLS) values for the maintenance of lateral and longitudinal separation standards. The examination period covered is 1 January 2013 through 31 December 2013.

G.2 BACKGROUND

G.2.1 The six South China Sea routes – L642, M771, N892, L625, N884 and M767 – were introduced in November 2001 in order to relieve congestion in the airspace. At the same time, State approval for Required Navigation Performance 10 (RNP 10) (now RNAV 10 under performance-based navigation (PBN) terminology) became mandatory for operation at or above flight 290 (FL 290).

G.2.2 This performance requirement was the basis for employing a minimum lateral separation standard of 60 NM between-route centerlines. As shown in Table G-1*, the six routes are organized into three route-pairs to serve principal origin destination points, no pre-departure clearance (No-pre-departure clearance (PDC)) flight levels by route and some information about routes crossing the RNAV routes.

G.2.3 The longitudinal separation minimum published for the 6 routes in November 2001 was 10 minutes with Mach number technique (MNT), or 80 NM RNAV.

G.2.4 Radar monitoring of horizontal navigational performance was initiated with introduction of the RNAV routes. The enabling Letter of Agreement (LOA) — signed by China, Hong Kong, China, Indonesia, Malaysia, Singapore, Thailand, Vietnam, and Philippines — specified details concerning the categories of errors to be monitored and reported to Singapore on a monthly basis. The LOA also called for reporting associated counts of flights monitored.

* All tables are located at the end of this appendix.