International Civil Aviation Organization

The Nineteenth Meeting of the Regional Airspace Safety Monitoring Advisory Group (RASMAG/19)

Pattaya, Thailand, 27-30 May 2014

Agenda Item 3: Reports from Asia/Pacific RMAs and EMAs

JASMA HORIZONTAL SAFETY ASSESSMENT

(Presented by JASMA)

SUMMARY

This paper presents the results of the horizontal airspace safety assessment of the oceanic airspace of the Fukuoka Flight Information Region (FIR) for the year 2013(1st Jan.2013-31stDec.2013.)

1. INTRODUCTION

1.1 This paper provides the horizontal risk assessment results of FUKUOKA FIR oceanic airspace carried out by JASMA. The methods for the calculation are refined or amended couple of times for the past meetings. The simple year by year comparison does not always make sense. But the results have the coherence and we can safely assume that TLS are all met except operational errors. In this paper we report the risk results of three ATC separations, namely ;

a) Time based longitudinal separation. (10 minutes without Mach number technique)

b) Distance based longitudinal separation. (RNP4)

c) 50NM lateral separation.

We also report on RNP/RNAV report during the 2013.

For the calculation methods and parameters used, please refer to the Attachment to this paper.

2. ESTIMATED RISK VALUES

2.1 The report shows that for the oceanic airspace of Fukuoka, all target level of safety were met for the year 2013. But as for the operational risk it is well above TLS, and this is mainly of the extremely conservative assumption. The incomplete reports also poses difficult problem to estimates risk correctly. These reports often lack some of the vital information such as duration of the deviation or how far they were deviated.

2.2 The JASMA will continue to assess horizontal risk regularly and try to device the improved methods to evaluate the operational error. But it is very important to share the standard algorithm and procedure to estimate horizontal risk values. We also have to develop algorithm which systematically filter the erroneous data which have the direct and adverse effect on the calculated values. The technical error is small enough to be ignored so that estimated operational risks were shown in the following paragraphs.

10 MINUTES SEPARATION

2.3 **Table 1** shows calculation results of 10 minutes time based longitudinal separation without Mach number technique. The calculated values seem varies each year. But, this is mainly because of the changes in the algorithm used for calculation of the risk. The results satisfy TLS.

NOPAC Routes – estimated annual flying hours = 73690 hours ***(note: estimated hours based on 2013 traffic sample data)***			
Risk	**Risk Estimation**	**TLS**	**Remarks**
RASMAG 19 Longitudinal Time Risk	***$3.76x10^{-11}$***	*5.0×10^{-9}*	*Below TLS*
RASMAG 18 Longitudinal Time Risk	*$1.79x10^{-9}$*	*5.0×10^{-9}*	*Below TLS*
RASMAG 15Longitudinal Time Risk	*$1.78x10^{-11}$*	*5.0×10^{-9}*	*Below TLS*

Table 1: NOPAC time separation Risk Estimates

30NM SEPARATION FOR RNP4 AIRCRAFT

2.4 **Table 2** shows calculation results of 30NM distance based longitudinal separation collision risk estimates. The calculating algorism used for RASMAG 19's risk is developed and introduced at RASMAG MAWG/1 in HAWAII by Dr. Mori. The risks seem to be increasing. In the future ever increasing traffic volume might make it hard to meet TLS.

NOPAC Routes ADS-C aircraft – estimated annual flying hours = 73690 hours ***(note: estimated hours based on 2013 traffic sample data)***			
Risk	**Risk Estimation**	**TLS**	**Remarks**
RASMAG 19 Longitudinal 30NM Risk	***$1.28x10^{-10}$***	*5.0×10^{-9}*	*Below TLS*
RASMAG 18 Longitudinal 30NM Risk	*$1.73x10^{-12}$*	*5.0×10^{-9}*	*Below TLS*
RASMAG 17Longitudinal 30NM Risk	*$3.68x10^{-13}$*	*5.0×10^{-9}*	*Below TLS*

Table 2: Risk Estimates for RNP4 aircraft with 30NM distance based separation.

50NM LATERAL SEPARATION

2.5 **Table 3** shows collision risk for laterally separated aircraft in the NOPAC system. The values are well below TLS. The risk value might increase as the traffic volume increases, but for the duration the value will remain below TLS.

NOPAC Routes(EXCEPT G344) – estimated annual flying hours = 43895.hours ***(note: estimated hours based on 2013 traffic sample data)***			
Risk	**Risk Estimation**	**TLS**	**Remarks**
RASMAG 19 Lateral Risk	***5.9889×10^{-15}***	*5.0×10^{-9}*	*Below TLS*
RASMAG 18 Lateral Risk	*3.90081×10^{-15}*	*5.0×10^{-9}*	*Below TLS*
RASMAG 17Lateral Risk	*4.13733×10^{-15}*	*5.0×10^{-9}*	*Below TLS*

Table 3: Lateral separation Risk Estimates for NOPAC.

LLD consideration from RNP/RNAV DEVIATION REPORTs

2.6 **Table 4** shows operational risk caused by LLD. We made some refinement but the result still does not satisfy TLS. There were only three reports which are flight crew waypoint insertion error categorized as C, flight plan followed rather than ATC clearance as categorized as B and deviate without ATC clearance categorized as A according to the EMA HANDBOOK classification of navigation errors. These events occurred in the not congested airspace and no lack of ATC separation but deviations are far and wide.

NOPAC Routes – estimated annual flying hours = 73690 hours ***(note: estimated hours based on Dec 2013 traffic sample data)***			
Risk	**Risk Estimation**	**TLS**	**Remarks**
RASMAG 19 Operational Risk	***9.40 x 10^{-6}***	*5.0 x 10^{-9}*	*Above TLS*
RASMAG 18 Operational Risk	*1.78 x 10^{-3}*	*5.0 x 10^{-9}*	*Above TLS*

Table 4: Operational Risk Estimates caused by LLD.

2.7 **Figure 1** shows airway NOPAC routes under consideration for this estimation. .

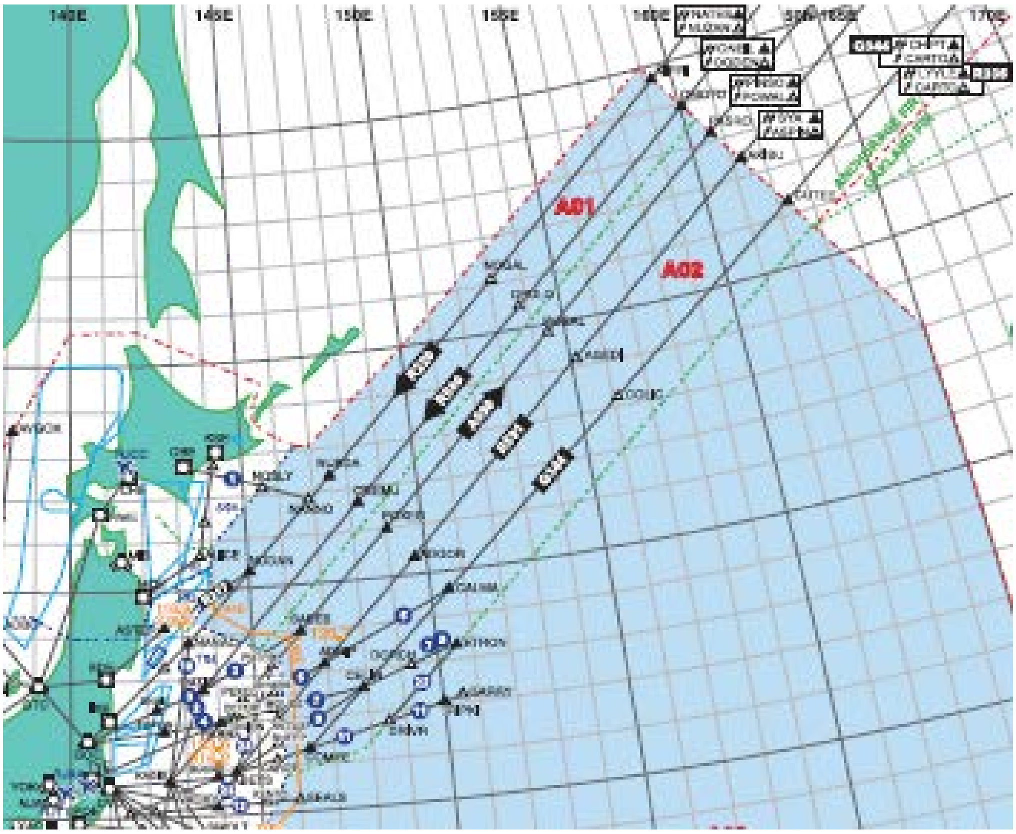

Figure 1: FUKUOKA FIR and NOPAC routes.

3. ACTION BY THE MEETING

3.1 The meeting is invited to:

a) note the information contained in this paper; and

b) Discuss the results of the airspace safety oversight presented in this working paper and the attached documentation.

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ATTACHMENT to WP11

HORIZONTAL RISK ASSESSMENT FOR FUKUOKA
FLIGHT INFORMATION REGION OCEANIC AREA

1. INTRODUCTION

1.1 This attachment details on CRM used in the WP HORIZONTAL SAFETY ASSEMENT. To evaluate collision risk values we have to take several things into consideration.

1.2 *Standardization of the CRM and calculating procedure.* For the past meetings we produced several reports on horizontal collision risk estimates. Each time we used somewhat different models or procedures. The models were refined and we could produce more realistic and precise estimates. However when we come to consider the trends and try to act proactive the calculated results will not give the coherent data set. To work on the calculated results we need standardization of the CRM algorithm and calculating procedure.

1.3 *Co-existence of variety of routing* system also poses some practical difficulties when calculating the risk values.

There are 15 fixed oceanic ATS routes. The NOPAC route consists of 5 routes, namely R220, R580, A590, R591 and G344. They link Japan with Alaskan and northern American cities through Anchorage. Ten southern oceanic ATS routes which link Japan with Southeast Asia/South Pacific through Oakland/Manila FIRs. Those are A590, R595, R584, A339, G339, A597, B586, A337, B452 and G223

There are also non-fixed routes called PACOTS (Pacific Organized Track System). PACOTS route will be designed daily by, mainly, considering weather conditions along the track.

User Preferred Routes (UPR) are also flexible tracks but, they designed by the operators to optimize the individual flight.

These flexible routing systems are expected to reduce greatly the consumption of fuel and curtail Co2 emission by shortening the flight distance and increasing the opportunity to have the optimal altitude.

But the flexibilities in the track designing causes difficulties assessing collision risk. We might as well consider the more general risk criteria such as traffic density in the future.

The other problem, this might only be true to Japanese ATC systems, but these routes selections are not well recorded in the ATC system journals. Presently there is no easy way to identify daily changing flexible route systems from the system journal. This is an obstacle to calculate the collision risk with consideration of their route structures.

Figure 1. shows oceanic routes in FUKUOKA FIR.

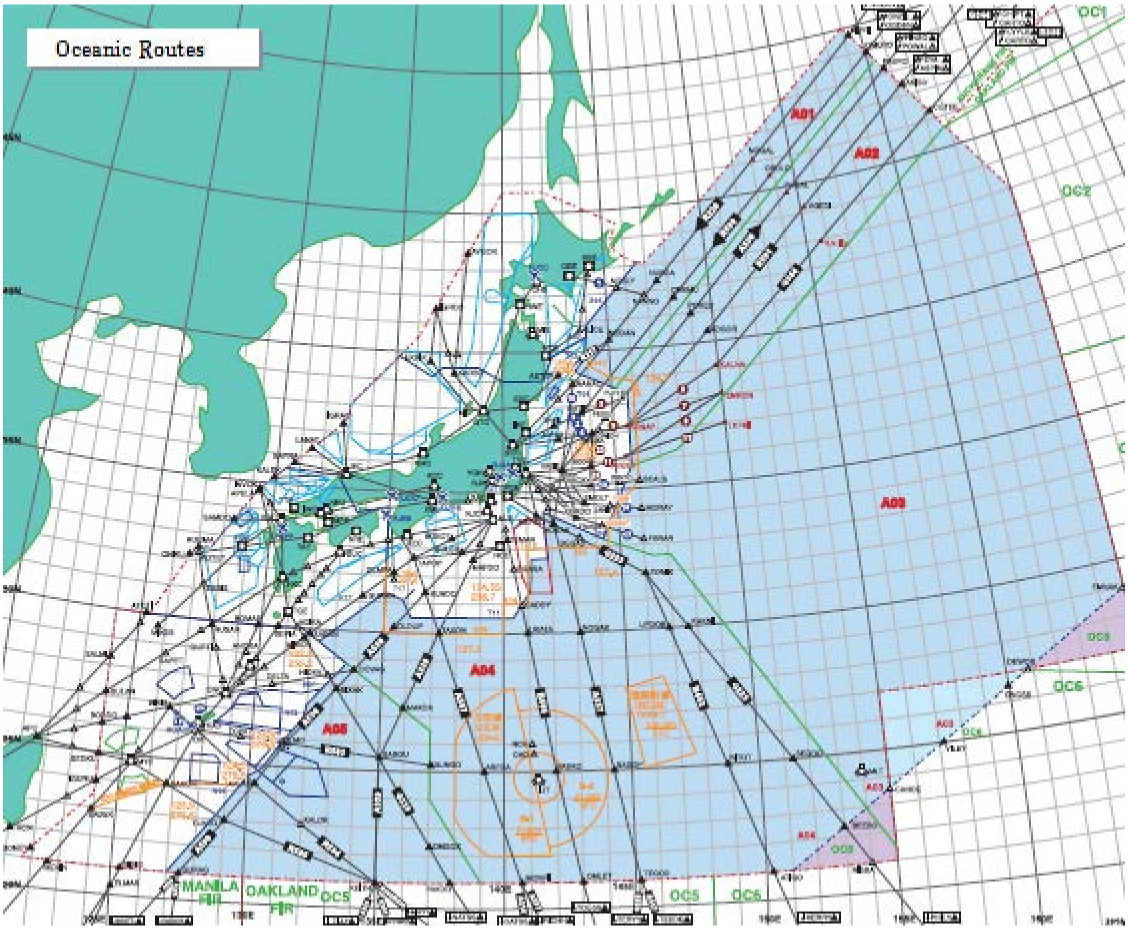


Figure 1: Oceanic routes in FUKUOKA FIR

1.4 *There are several types of ATC separations applicable in the oceanic area*. We have to devise CRMs for each specific separations. **Table 1** shows the longitudinal separation minima applicable to the aircraft-pairs in the oceanic ATS routes in Fukuoka FIR

Longitudinal separation minima			
	RNP4 aircraft (ADS-C/CPDLC)	RNP10 aircraft (ADS-C/CPDLC)	Other aircraft
RNP4 aircraft (ADS-C/CPDLC)	30NM	50NM	10min*
RNP10 aircraft (ADS-C/CPDLC)	50NM	50NM	10min*
Other aircraft	10min*	10min*	10min*

Table 1: Longitudinal separation minima in the oceanic airspace of Fukuoka FIR
* Not applicable on PACOTS/UPR without MNT.

1.5 *The Data screening criteria must also be considered.* The data quality directly affects collision result. So the screening or filtering data have vital importance. (See typical case example. in section 2.3)

2. COLLISION RISK FOR TIME BASED ATC SEPARATION

2.1 Time based separations are still widely used but will give way to the distance based separation in the future. Below is the general description of algorithm for the risk estimates for the ten minutes time based ATC separation without Mach number technique.

2.2 The CRM developed by Fujita and amended by Mori at ENRI is used for this calculation. The probability that the longitudinal separation will be infringed when the initial time separation is equal to *t* (defined *p(t)*) is calculated using the following expression. (1)

$$P_x(t) = \int_{\tau}^{\infty} l_m(\tau)d\tau \qquad (1)$$

Figure 2 shows initial time distribution between the flights pairs.

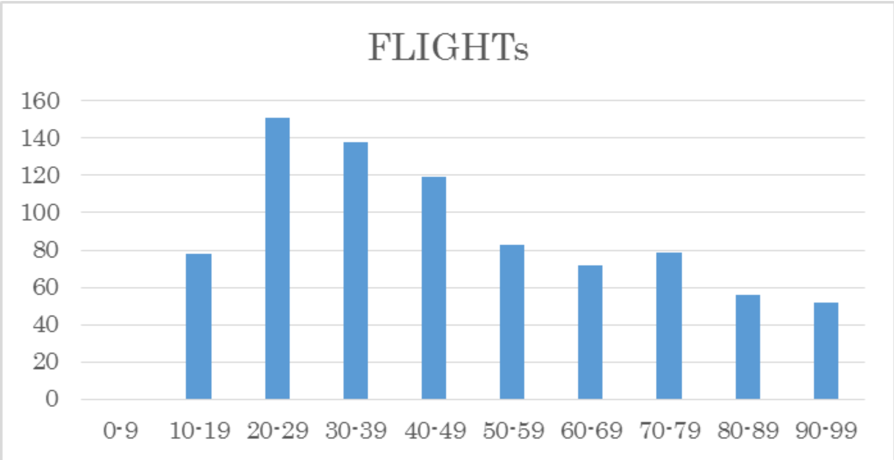
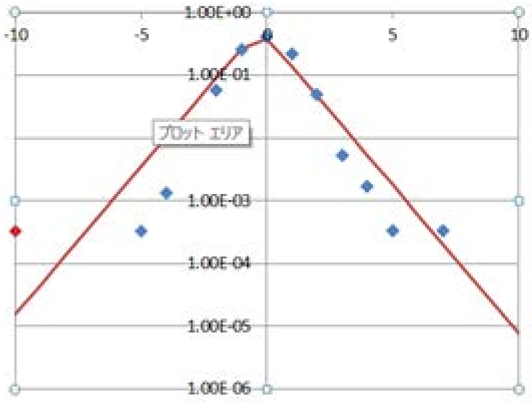


Figure 2: Initial time separation distribution.

Considering a three dimensional collision, the expected risk of collision *Nax*, which is defined as the expected number of accidents per flight hour due to loss of assigned longitudinal separation, is calculated by the following expression. (2)

$$N_{ax} = P_y(0)P_z(0)\frac{2\lambda_x}{|\bar{x}|T}\left(\frac{|\bar{x}|}{2\lambda_x} + \frac{|\bar{y}(0)|}{2\lambda_y} + \frac{|\overline{z(0)}|}{2\lambda_z}\sum E_x(t)P_x(t)\right. \qquad (2)$$

2.3 Below is an example of loss distribution fitting. The blue squires are value of loss times. Red and blue lines are theoretical distribution fitted by LSM. (The scale is logarithmic)



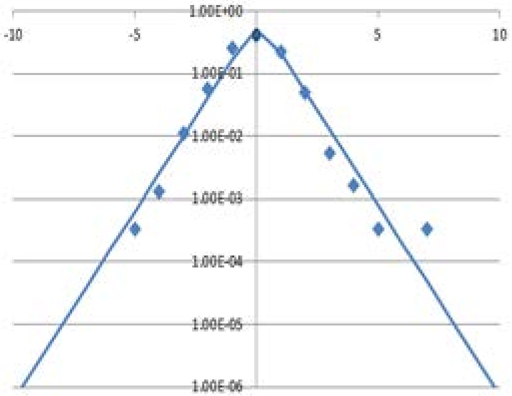


Figure 3: with stray value "-10" (red dot) **Figure 4:** without stray value.

Figure 3 on the right shows a stray value "-10". Because of the this the theoretical distribution seemes not quite fit to the actual distribution. Without this stray value theoretical distribution fits much better. **Figure 4.** This corresponds diference in parameters of DE distribution. The parameters with an astray value are μ=-0.3115 λ=0.9216 while the parameters without an astray value are μ=-0.0537 λ=0.6384. This results in difference in risck values. The risck value with astray value is 1.06915E-08 and dose not satisfy TLS while risk after eliminating astray value is 7.730E-10 and this satisfys the TLS.

2.4 **Table 2** explain parameters used in this calculation.

	Parameter Definition	**Parameter Value**	**Source for Value**
Py(0)	Probability that two aircraft on the same track are in lateral overlap	0.0196	SASP-WG/WHL/13-IP/08
Pz(0)	Probability of vertical overlap in operational risk estimation for the aircraft flying as a same flight level	0.54	ICAO SASP safety assessment
$\overline{\lvert\dot{y}(0)\rvert}$	The average relative speed between two aircraft, across track.	1kt	EMA handbook
$\overline{\lvert\dot{z}(0)\rvert}$	Average vertical speed of aircraft pairs	1.5 kt	ICAO SASP safety assessment
λx	Average aircraft length	0.0272 nm	JASMA Dec.2013
λy	Average aircraft width	0.00250nm	JASMA Dec.2013
λz	Average aircraft height	0.0080nm	JASMA Dec.2013
T	The average time to fly the segment.	0.69h	FDPS data (NOPAC) 2013
Ex(t)	The proportion of aircraft initial separation	----	----
$P_x(t)$	The probability of the loss of longitudinal separation.	----	----

Table 2: Parameters for Time based risk calculation model.

3. COLLISION RISK FOR DISTANCE BASED ATC SEPARATION

3.1 This is the CRM for 30 NM longitudinal separation minimum with RNP4 and ADS-C capability in the NOPAC routes. The NOPAC is the busiest airway in the oceanic routes system. If the risk estimates for the NOPAC satisfy the TLS then we can safely assume that the TLS in the whole FUKUOKA oceanic FIR will meet TLS.

This Risk estimation was done under following assumptions.

1. Aircraft under consideration are the flights in the NOPAC routes with 30NM longitudinal separation with RNP4. The relative frequency Ex(x) was estimated by analyzing flight in the NOPAC routes for the year 2013.
2. All aircraft equipped with GPS.
3. The position errors of the aircraft are estimated by comparison of ADS-C position estimate and actual reported position. These position errors are converted to the speed errors.
4. Uplink times are collected by analyzing ODP’s DLCS data.
5. Time required for collision resolution by ATC is given as a constant.

3.2 CRM for distance based separation.

* Refer to the more detailed explanation on the calculation method to RASMAG/15 WP/22, RASMAG/16-WP/03 and MAWG/1-WP/7.

3.3 Let $f_x(d;v_1,v_2,t,\Delta T,T)$ be the probability density function of position error “d”. The values of v_1, v_2, t, ΔT and T are constants in this formula. The longitudinal overlapping probability of a typical aircraft pair is given by the following formula (3).

$$P_x(x;\tau) = \frac{1}{T(T+\tau)} \int_0^T \int_0^{T+\tau} \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \int_{x-\lambda x}^{x+\lambda x} f_d(x;v_1,v_2,t,\Delta T)\, f_v(v_1)\, f_v(v_2)\, dx\, dv_1\, dv_2\, dt\, d(\Delta T) \qquad (3)$$

The individual parameters for the equation (3) and their definitions are given in **Table 3**.

Parameter	Description	Parameter Value	Source for Value
$P_x(x;\tau)$	Longitudinal overlap probability. Mean probability that a typical aircraft pair which is nominally x NM separated on the same route at the same flight level overlaps in the longitudinal dimension.	----	----
$f_v(V)$	Probability densities function of longitudinal speed prediction errors. (Prediction is done by ODP using the ADS-C message down linked from the aircraft) It is determined by the accuracy of position prediction by the aircraft, the performance of the ground ATC system interpolation/extrapolation function and so on.	----	----
$f_x(d;v_1,v_2,t,\Delta T,T)$	Probability density function of longitudinal position errors d at the given v_1 v_2, t and ΔT. It is calculated by means of equation (1).	----	----

T	Reporting interval of ADS position report.	576sec	Standard Oceanic ADS-C Reporting Interval
τ	Time required for the resolution of a potential collision.	----	set values
λ_x	Average aircraft length	0.0250NM	JASMA Dec. 2013

Table 3: Parameters in Equation (3)

Using the longitudinal overlapping probability, the collision risk is estimated by the following formula (4).

$$N_{ax}(x;\tau) = 2 \cdot P_y(0) \cdot P_z(0) \cdot P_x(x;\tau) \cdot \left(\frac{V_{rx}}{2\lambda_x} + \frac{V_{ry}}{2\lambda_y} + \frac{V_{rz}}{2\lambda_z} \right) \tag{4}$$

The individual parameters for the equation (4) and their definitions are given in **Table 4.**

Parameter	Description	**Parameter Value**	**Source for Value**
$N_{ax}(x;\tau)$	Collision risk of a typical aircraft pair on the same route at the same flight level whose nominal separation is x (NM). Remember that τ is the time required for the resolution of a potential collision.	----	----
$P_y(0)$	Lateral overlap probability. Probability that an aircraft pair on the same route overlaps in the lateral dimension.	0.0196	SASP-WG/WHL/13-IP/08
$P_z(0)$	Vertical overlap probability. Probability that an aircraft pair at the same flight level overlaps in the vertical dimension.	0.54	RVSM/TF-9-IP/2
$V_{rx}(x)$	Average longitudinal relative velocity of aircraft pairs which are about losing their longitudinal separation in spite of the nominal x NM separation.	----	Assumption $V_{rx} = \frac{x}{T+\tau}$
V_{ry}	Average lateral relative velocity of aircraft pairs on the same route.	1knot	EMA HAND BOOK
V_{rz}	Average vertical relative velocity of aircraft pairs at the same flight level.	1.5knot	ICAO SASP
λ_y	Average aircraft length	0.0250NM	JASMA Dec. 2013
λ_z	Average aircraft height	0.0080NM	JASMA Dec. 2013

Table 4: Parameters in Equation (4)

In the previous equation, the distribution of nominal separation is fixed. When relative frequency for the aircraft pair that are flying on the same route and same altitude with the nominal (the displayed separation of the aircraft on the ODP consoles) separation of x(s) are given, collision estimation with resolution time is estimated by equation (5).

$$N_{ax}(\tau) = \sum_{x=0}^{\infty} N_{ax}(x;\tau) E_x(x) \tag{5}$$

The individual parameters for the equation (5) and their definitions are given in **Table 5**.

Parameter	Description	**Parameter Value**	**Source for Value**
$N_{ax}(x,\tau)$	Collision risk value. Where τ is the time required for the resolution of a potential collision.	----	----
$E_x(x)$	The relative frequency for the aircraft pair that are flying on the same route and same altitude with the nominal separation of x.	----	Estimated from flight Plan data and ADS-C position reports

Table 5: Parameters in Equation (5)

3.4 Finally CPDLC uplink time is taken into consideration. The average collision risk with respect to this parameter is given by

$$N_{ax} = \sum_{\tau=0}^{\infty} N_{ax}(\tau)E_{\tau}(\tau) \qquad (6)$$

The individual parameters for the equation (5) and their definitions are given in **Table 6**.

Parameter	Description	**Parameter Value**	**Source for Value**
N_{ax}	Collision risk in the considered ADS-Environment.	----	----
$E_\tau(\tau)$	The relative frequency of time required to resolve a potential collision.	----	Fixed value by ENRI.

Table 6: Parameters in Equation (6)

For the time to collision avoidance operation by the controller, we used the value proposed by ENRI at MAWG/1-WP/7. The maximum total time for collision avoidance instructions is estimated by value 405 seconds which includes initial overdue of 180 seconds.

4. COLLISION RISK FOR 50NM ATC LATERAL SEPARATION

4.1 The total Number of Flight Hours and Passing Frequencies are shown in **Table 7**. Note that passing frequencies between airway R220 and R580 is relatively small. Because R220 and R580 are both westbound only for all the time. So passing occurs only when catching up occurs. On the other hand passing frequency between R580 and A590 is large because R220 is used for westbound while A590 is used east bound. The R591 is eastbound only unless designated as westbound PACOTS track.

	Flight Hours		Passing Frequencies		
Airways(Traffic Volume)	East Bounds	West Bounds	Same E-Bounds	Same W-Bounds	Opposite Direction
R220(18877)	0	28105.8			
			0	333	0
R580(18870)	1.88333	11694.1			
			0	0	6228.5
A590(21992)	27610.7	0			
			92	0	890.5
R591(22000)	4830.87	1446.43			
			0	0	0

Table 7: Flight Hours and Passing Frequencies

4.2 The formulas of the lateral collision risk model used in assessing the safety of operations on NOPAC routes are:

$$N_{ay}(same) = P_z(0)P_y(S_y)\frac{2\lambda_x}{\overline{|\Delta V|}} N_x^y(same)\left[\frac{\overline{|\Delta V|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right] \quad (7)$$

$$N_{ay}(opposite) = P_z(0)P_y(S_y)\frac{2\lambda_x}{2\overline{|V|}} N_x^y(opp)\left[\frac{2\overline{|V|}}{2\lambda_x} + \frac{\overline{|\dot{y}|}}{2\lambda_y} + \frac{\overline{|\dot{z}|}}{2\lambda_z}\right] \quad (8)$$

$$N_{ay} = N_{ay}(same) + N_{ay}(opposite) \quad (9)$$

2.12.2 T**able 8** summarizes the value and source material for estimating the parameter values of the following Collision Risk Model (CRM) used to conduct safety oversight for the RNP-10 based 50NM lateral separation minimum of NOPAC routes.

Parameter Symbol	**Parameter Definition**	**Parameter Value**	**Source for Value**
$\overline{\|V\|}$	Individual-aircraft along track speed	480 knot	Value often used
$\overline{\|\Delta V\|}$	Average along track speed of aircraft pairs	28.9 knot	Kushiro Air Route Surveillance Radar data (R220 route, NOPAC,Apr. 1994)
$\overline{\|\dot{y}\|}$	Average cross track speed of aircraft pairs	42.22 knot	Doc.9689 1st eds. Appendix 13
$\overline{\|\dot{z}\|}$	Average vertical speed of aircraft pairs	1.5 knot	Value often used
λx	Average aircraft length	0.0272 nm	JASMA (December 2013)
λy	Average aircraft width	0.0250 nm	JASMA (December 2013)
λz	Average aircraft height	0.0080nm	JASMA (December 2013)
Nix(same)	The passing frequency of aircraft pair assigned to the adjacent flight levels under the same direction traffic	1.15×10^{-2}	FDPS data (NOPAC, December 2013)
Nix(opp)	The passing frequency of aircraft pair assigned to the adjacent flight levels under the opposite direction traffic	19.32×10^{-2}	FDPS data (NOPAC, December 2013)
Pz(0)	Probability of vertical overlap in operational risk estimation for the aircraft flying as a same flight level	0.54	Value often used (shown in RVSM/TF-9-IP/2)
Py(50)	Probability that two aircraft on the same track are in lateral overlap	4.71×10^{-14}	Using the data of secondary surveillance radar obtained by the Kushiro Air Route Surveillance radar (R220 route, DDE model, December 2009)

Table 8: Estimates of the parameters in the CRM

5. LLD considerations

5.1 Three cases of RNP deviations were reported from ATMC (Air Traffic Management Center) and TOKYO ACC during the year 2013.

NO.	DATE	to	POSITION	UTC	TYPE	A-ALT	Dev(MAX)	DURATION	DURATION ESTIMATED	CATEGORY
1	2013/02/08	ATMC	35N150E-34N160E-32N170E	12:20	B774	FL350	120NM(North)	?	15MIN	C
2	2013/03/25	ACC	NODAN-ASTER	17:44	B77W	FL360	25NM(South)	15min		B
3	2013/04/24	ATMC	44N160E-KALNA	03:44	A332	FL360	50NM(North)	?	44MIN	A

NO1. Pilot data entry error. The flight crew manually entered route data into FMC. During the data entry one of the way point was entered incorrectly two degrees north of the original route. One of the relief officers plotted the course on the plotting chart; however the captain failed to verify the chart before departure nor after departure. An oceanic controller at ATMC noticed the deviation just before exiting from FUKUOKA FIR to adjacent FIR. The controller took remedial measures and handed the controlling responsibility over to the adjacent FIR. No actual harm was done.

NO2. TOKYO ACC was advised by the ADS monitoring controller at FUKUOKA ATMC oceanic sector that the traffic was deviating from flight planned path. An ACC controller confirmed to the pilot and found out the aircraft was not flying flight planned route submitted to TOKYO ACC. There might be a possibility that the original route clearance was also amended but that was not confirmed.

NO3. Pilot deviated from original routes without ATC clearance. An ATMC controller noticed the deviation by CPDLC position reporting message. The controller confirmed to the pilot. For this inquiry pilot requested deviation 20NM right of the course. But from the position report it was already deviated almost 50NM right of course. The pilot requested direct flight from the deviated position and it was granted. No other traffic was involved in this case.

5.2 With following supposition operational estimate is calculated.

*All LLD occurred in the NOPAC system which is the busiest track in the oceanic area.

*ALL routes are run parallel and separated by 50NM each other. Theoretical distribution used by lateral collision risk was used. Py(x) are calculated according to the deviated distance x.

Py(0)	Py(10)	Py(20)	Py(30)	Py(40)	Py(50)
4.84159E-02	2.76594E-05	3.38430E-06	8.56447E-07	2.13323E-07	5.31339E-08

*Aircraft on the adjacent route were flying just on the routes.

*Duration was estimated by the report. The duration time after the situation was resolved is not counted.

6. ACTION BY THE MEETING

6.1 The meeting is invited to:

c) note the information contained in this paper; and
d) discuss any relevant matters as appropriate.

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